Titanate Based Perovskite Anode Material for Solid Oxide Fuel Cell

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By

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DEDICATION

This thesis is dedicated to my beloved father, Muhammad Ishaq (late) and my mother who inspired scientific thinking in my life, stand by me when things look bleak, gave me the greatest gift i.e. They believed on me. After this I dedicate this to my all family members.Who has been a constant source of inspiration and guidance, offering me kind assistance and support throughout this project. Without their invaluable contributions, this endeavour would have remained a mere dream.

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Bilal Ishaq

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LIST OF ABBREVIATIONS

SOFC	Solid oxide fuel cell
AFC	Alkaline fuel cell
PEMFC	Polymer electrolyte membrane fuel cell
MCFC	Molten carbonate fuel cell
PAFC	Phosphoric acid fuel cell
FC	Fuel cell
MEC	Mixed ionic and electronic conductor
AEBD	Alternate energy development board
CFC	Chlorofluorocarbons
DC	Direct current
MW	Mega watt
TWH	Terawatt hour
ICE	Iinternal combustion engine
SEM	Sscanning electron microscope
XRD	X ray diffraction
$MWcm^{-2}$	Mille watts per square centimetre
V	Volt
La	Lanthanum
Sr	Strontium
Mn	Manganese
TiO	Titanium oxide
Nm	Nanometre
Mm	Millimetre

ABSTRACT

High-temperature and structural characteristics of Cu-doped $LaSrTiO_3$ (LSCT) make it one of the sole anode materials for solid oxide fuel cells (SOFCs). It is pertinent to note that this current work is devoted to the synthesis of LSCT using sol-gel technology, which enables to control over morphology and phase constitution of compound. Analysis of the material surface topography, by SEM, indicated an average crystallite size of less than 30 nm. X-ray diffraction (XRD) identified the existence of a cubic perovskite structure for the synthesized material and from the Scherrer equation the crystalline size was estimated to be around 20 nm. Electrical conductivity measurements made using the four-probe method visually established that LSCT can generate a maximal power density of 4. 21 S/cm^{-1} at 600°C. These results exhibit that the material is a promising candidate for anode applications in SOFCs since it displayed both high strength and high electrical conductivity at high temperatures. It seems that the incorporation of Cu into the $LaSrTiO_3$ crystal structure may significantly alter the general conductivity and catalytic properties of this material, making it suitable for the further modification of fuel cells.

CHAPTER 1

INTRODUCTION

Thus, the inadequacy of natural resources including oil, natural gas and coal has resulted in energy crisis that is affecting the economy and social infrastructure of countries worldwide. The requirement for energy is increasing rapidly due to overpopulation, improvements in lifestyle, industrial and agricultural growth, transportation needs, and other factors. This has put pressure on natural resources, leading to an increase in energy prices, which has affected the economy and social infrastructure of countries worldwide [1]. By burning of fossil fuels, the carbon cycle is being changed especially through injection of CO_2 into the atmosphere. CO_2, as well as CH_4 and NO, is a greenhouse gases maintaining the Earth's surface temperature between lethal and uninhabitable limits and promoting plant photosynthesis. Nonetheless, rising to 093 ppm since the start of the Industrial Modification Age, carbon dioxide levels now have an impact on climate changes. To reduce the pressure on natural resources, many countries are exploring alternative energy origin like biofuel, biogas, solar energy, tidal energy, wind energy, hydropower, and geothermal power. Renewable and non-renewable energy sources can be used to overcome the burden of electrical energy, and fuel cell technology can be used today. Fuel cells offer numerous benefits above traditional methods of power generation, such as high energy density, proficiency, adjustability, and fuel elasticity However, Alternative energy sources such as small-hydropower, solar cell, wind, geothermal, biomass, ocean, and tidal projects are increasingly favored as sustainable, long-term options for energy production. The development of these alternatives is crucial for the clean and efficient utilization of energy under varying condition [2]. Trust on coal and oil developing, deforestation remains a worry The growing reliance of the region as well with national promises to reduce discharges committed towards cleaner energy sources. Supply: Supply for coal is partly driven by its relative abundance, and the facts that it's cheaper than oil/gas/renewable energy. Unlike renewable energy projects, coal-fired plants are simpler and far easier to finance. Though the region is seeing an influx in renewables, particularly solar and wind their potential output means countries are still on fossil fuels. Such fuels are needed to provide electricity and 80 percent of which goes into cooking and transport, yet the use is growing as governments seek extended access for populations. The IMF indeed projected that 65 million Southeast Asian lack electricity and 251 million use biomass, such as fuel and animal organic, for preparation fuel Global demand for energy is growing swiftly, because of population and economical growth, specially in developing market economies. To backing countries, try to achieve economic growth and development, while certifying that natural possession continue to provide the resources and environmental services on which well-being trusts, a flexible policy framework that can be made-to-order to different country condition and phase of development is proposed. The strategic plan of a new policy emphasizes a more energy efficient, renewable energy source based power generation (solar,wind) and a complete conversion of all modes of transport minimizing coal, oil and natural gas usage. Innovative concepts and new structures will be important in advancing to the next level of energy sustainability. The enhancement of energy alternatives is important to ensure effective energy conservation under such different circumstances. Small-hydropower, solar, wind, geothermal, biomass, ocean, tidal program are accepted as appropriate long term energy generation prospects. Nevertheless, the shift to these alternatives is prone to some constraints. As an illustration the United States. The collective population of the country represents slight over 4.0 percent of the world population yet cumulate about 17 percent of the worlds energy consumption. The gross average carbon emissions per head are among some of the high in the world. Currently, the USA, Australia and Canadian resident utilizes approximately 200 times more carbon than outrageously poor yet, rapidly developing nation residents in sub-Saharan Africa such as Chad, Niger and the Central African Republic Combining several population estimates into climate models assuming that this leads to high emissions reduction of the natural resources like oil, natural gas, coal have led to energy crisis causing detriment to the economy and infrastructure of several countries in the world. Pakistan is facing an energy crisis, Pakistan's energy demand is projected to grow exponentially, with an 8-fold rise by 2030 and a 20-fold increase by 2050 [3]. This quick growth, at a rate exceeding 9% annually, highlights the pressing need for sustainable energy solutions in the country. The current energy structure in Pakistan is heavily dependent on thermal origin, such as coal, oil, and natural gas, which are not only costly but also facing severe supply shortages. Additionally, the share of hydroelectricity has importantly decreased in recent years, while renewable energy sources, particularly solar power, possesses the capability to meet these challenges. Solar energy appears as a competitively priced technology worldwide, with the global ability of solar photovoltaic (PV) reaching 402 gigawatts by the end of 2017, accordant to the International Energy Agency. This rapid growth in solar energy adoption underscores its viability as a sustainable solution to Pakistan's energy crisis [4]. By leveraging its abundant solar resources and the cost-effectiveness of solar technology. It will further grow just about 580 GW and lead the renewable electricity volume evolution. The oil and gas industry is also facing challenges due to geopolitical and macroeconomic uncertainty, supply disruptions, and price volatility. However, the industry is focused on securing supply in the short term while conversion to cleaner energy in the long term. The industry is positive about the future, with a healthy balance sheet and continued capital discipline. For almost 2 decades the European commission has conducted research programs on solar energy aimed at reducing carbon emission and pollution, enhancing energy security and expanding energy sources of European nations. The global weighted-average level cost of electricity for recently commissioned utility-scale solar photovoltaic (PV) projects experienced a substantial 85.0% decrease between 2010 and 2020. In comparison, the cost reductions for concentrated solar power (CSP) stood at 68.0%, onshore wind at 56.0%, and offshore wind at 48.0%. This significant cost decline underscores the development competitiveness of renewable energy sources, positioning them as the primary choice for capacity expansions in the power sector across various nations. Solar and wind technologies have solidified their leading impression over time, with the recent surge in fossil fuel prices further enhancing the economic practicality of renewable power solutions. This trend highlights the increasingly favourable economic outlook for renewable energy in the global energy backdrop. The improvement of solar energy in Pakistan is crucial for the clean and economic utilization of energy under varying conditions. The combined installed volume of solar reached 843.0 GW globally by the end of 2021, with 133 GW of capacity commissioned in 2021 alone, with 57.0% of the commencement in Asia. The development of solar energy in Pakistan can help the country to cut down its habituation on fossil fuels and move towards a more bearable energy upcoming. Pakistan is facing an energy crisis due to the increasing demand for energy, which is growing by more than 9% annually. The leading reason for the energy crisis in Pakistan the energy structure is primarily dependent on thermal resources, including coal, oil, and natural gas, which are costly and under immense pressure of shortage. As mentioned, the enhancement of solar energy in Pakistan is important for the proper and efficient production of energy in different circumstances. It is not an easy exercise to begin the shift to solar energy and this will call for the following changes; the use of energy has to increase much faster, producing it from renewable resources, and electrifying transport to scale back the usage of coal, oil, and natural gas. Long term the oil and gas industry is also moving to clean energy which underscores the need to come up with other sources of energy such as hybrid power and fuel cell technologies to build the foundation for a cleaner future.

1.1. Renewable energy sources

Energy is a very important part of sustainable improvement, and sustainable energy systems are necessary for achieving sustainable development. While renewable energy sources have made significant progress in the last few decades, with double-digit percentages of renewable energy penetration in electricity supply in various countries, many other countries and sectors like transportation are still in the initial stages of renewable energy adoption [5].The overall renewable and nonrenewable energy sources are show in fig 1.1.

1.1.1. Wind Energy

Wind farms have been positively mounted on-shore since the 1990s, masking decide with the quality wind resources. Some of the set up wind generators have surpassed 1/2 of their anticipated lifespan and agreement durations, however the mastering curve of wind electricity generation has advanced exponentially seeing that then this focuses on the authentic valorization of a standing wind farm and the efficacy of the exploitation of the site's wind aid [6].

1.1.2. Solar Energy

Solar energy is a low-cost and plentiful supply of strength that is healthy for numerous programs. The preservation cost for solar electricity systems is also low however, the primary drawback of solar strength is that it is problem to climate irregularity, which means that that it requires an energy storage gadget to make certain a non-stop supply of electricity [7].

1.1.3. Biomass Energy

By 2050, it's miles predictable that 90% of the sectors can also belong to in growing international locations consequently, biomass strength is likely to remain a huge power feed stock. Biomass sources can be used for direct heating in industrial or domestic situation, within the manufacturing of steam for energy technology, or to supply gaseous and liquid fuels [8]

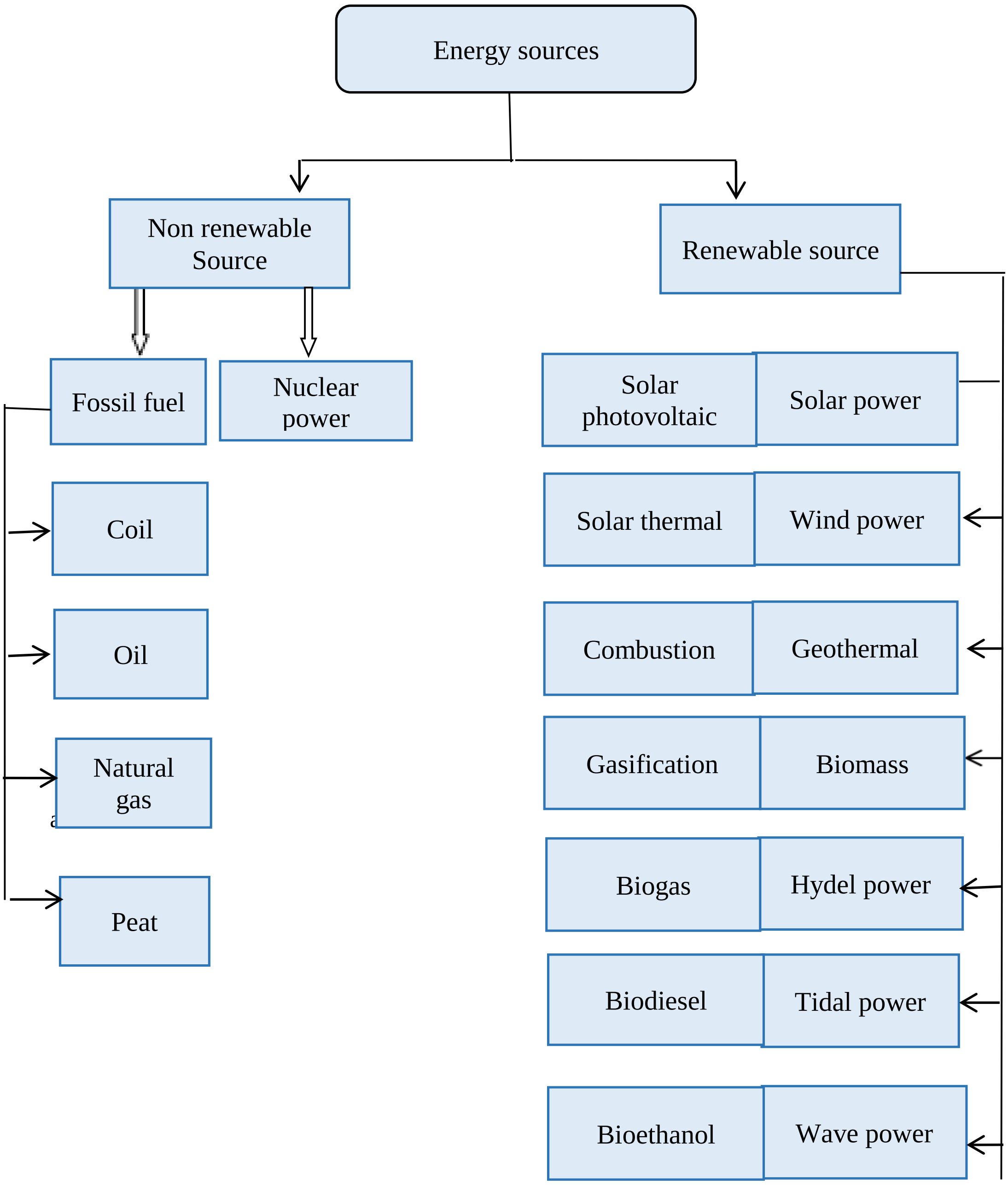
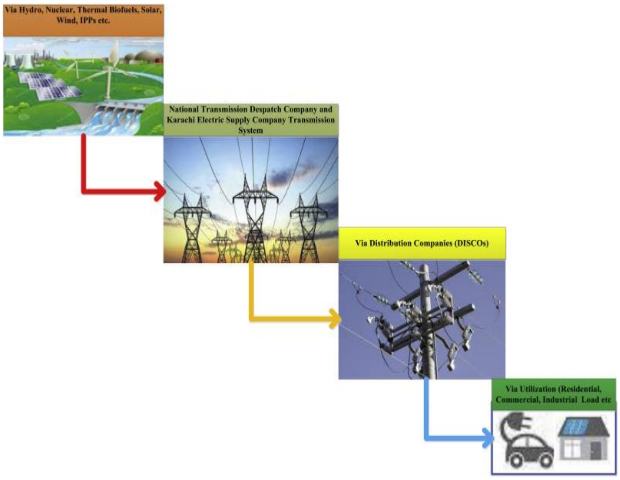


Fig1.1: Renewable and non-renewable energy source

1.2. Power sector organization mission in Pakistan

The production, distribution, and consumption of electricity in Pakistan is a complex process that involves several stages and various companies. By 2022, the nation's total installed electricity generation capacity reached 41,557 MW, with over 80% of the population having access to power. The country’s electricity sector is primarily overseen by two main public organizations: Development Authority (WAPDA) and Karachi Electric (formerly KESC) [9]. Which oversee generation, transmission, distribution, and retail supply. In addition, approximately 42 power producers (IPPs) play an important role in supplying electricity to national grid. The energy breakdown in 2022 was 63% thermal (fossil fuels), 26% hydropower, 3% from renewable sources (wind, solar, and biomass), and 8% from nuclear energy. Pakistan aims to source 60% of its energy from renewables, including hydropower, by 2030. The country holds significant potential for electricity generation from Thar coal, hydro, wind, and solar energy. Despite increasing its power capacity, Pakistan continues to face electricity shortages and struggles to balance supply and demand. Moreover, the high reliance on fossil fuel capacity has led to rising electricity costs and concerns about achieving its climate targets fig1.2.



1.2: Fig Power sector organizations in Pakistan.

1.3. Fuel cell technology

Fuel cells produce electricity by transforming the chemical energy found in fuels through an electrochemical process, without producing harmful emissions. They offer several advantages over conventional power generation methods, such as higher energy density, efficiency, flexibility, and the capacity to utilize multiple types of fuels. Solid Oxide Fuel Cells (SOFCs) have demonstrated high effectiveness for electricity generation across many commercial applications. The efficiency and design of SOFCs are critical for their success. This research focuses on developing a cost-efficient, reliable, and durable anode material that could be used to create high-performing, eco-friendly SOFCs.The outlook for the oil and gas industry in 2023 is uncertain due to global political and economic challenges, supply chain disruptions, and price fluctuations [10]. However, the industry is focused on securing energy supplies in the short term while working toward cleaner energy solutions in the future. Despite the uncertainty, the industry maintains a positive outlook, with strong financial stability and continued capital discipline. Current trends emphasize the growing need for alternative energy sources and fuel cell technology, which are seen as critical in creating a sustainable energy future. Government policies are essential in decreasing reliance on fossil fuels. Significant investment and global cooperation are needed to encourage the advancements of different energy options and fossil cell technologies. These policies can help lower energy consumption, improve energy security, and fund the transition to sustainable energy without increasing costs. Governments must work together to create strategies that support a cleaner, more sustainable energy future. Fuel cells, with their numerous benefits, stand out as a key technology in this transition. Including:

i. High energy density

ii. High efficiency

iii. Adjustability

iv. Fuel flexibility

v. Low emissions

One key benefit is their ability to function at higher efficiencies compared to combustion engines. Fuel cells can directly transforms the chemical energy within the fuel into electrical energy with efficiency rate that can exceed 60%. This direct conversion process eliminates the need for intermediate steps, such as heat production and mechanical energy transformation, which have been essential in combustion-based systems, leading to higher overall efficiency.

Components of fuel cell

Three main components of FCs

FCs have three main constituents’ anode, cathode, and solid ceramic electrolyte.

Anode

Oxidation of the fuel (H_2) occurs at anode surface with the aid of a catalyst. Losing electrons from the fuel move through the circuit and generate current in the circuit.

$$2H_2 \longrightarrow 4H^+ + 4e^-$$

Cathode

The cathode distributes the oxygen on its surface it comes from air and conducts electrons from the circuit. After gaining electrons from the circuit the oxygen changed into oxygen ions which passed across the electrolyte and joined with hydrogen ions to form H_2O and heat as a by-product shown in fig 1.3.

$$O_2 + 4e^- + 4H^+ \longrightarrow 4H_2O$$

The overall fuel cell reaction is,

$$2H_2 + O_2 \longrightarrow 2H_2O$$

Electrolyte

The electrolyte helps determine the operative temperatures of the cell and allows the charged ions to pass from itself to maintain the electrical charge balance. The electrolyte can also act as the oxygen ions and proton conductor.

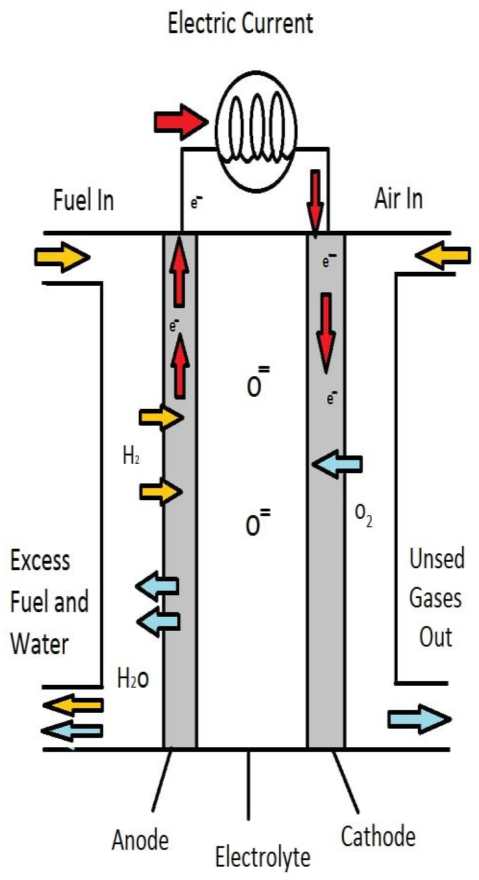


Fig 1.3: Hydrogen based fuel cell

1.4. The importance of alternative energy sources

Despite activity to promote renewable energies as an alternative to fossil fuels, fossil fuels continue to give significantly to universal electricity production. In 2017, fossil fuels contributed 72% worldwide electricity production, while renewable sources impart only 26%. The primary fossil fuels are coal, natural gas, and oil Renewable energy origin include geothermal, wind, solar, and hydroelectric power.

1.5. Types of fuel cell

1.5.1. Proton-exchange membrane fuel cell

Proton exchange membrane fuel cells (PEMFCs) have seen significant progress, driven by the growing demand for clean and sustainable energy. However, there are still several challenges at both the device and infrastructure levels that must be addressed before these fuel cells can be economically feasible for commercial scale. One of the key obstacles is increasing the power density of PEMFCs, with various global targets in place. For instance, Japan's New Energy and Industrial Technology Development Organization (NEDO) has set power density goals of 6 kilowatts per liter by 2030 and 9 kilowatts per liter by 2040 [11].To achieve these objectives, several technological innovations are being explored, particularly in enhancing the membrane electrode assembly (MEA) and its components. Improvements in water and thermal management, as well as new materials, are predicted to play a crucial role in next-generation PEMFCs, enabling higher power density. Addressing these challenges requires a thorough understanding of all aspects of PEMFC technology. Recent research has focused on innovative design approaches made possible by advances in micro- and nanofabrication techniques, such as inkjet printing, template-based patterning, and thin-film deposition. A promising development is the use of fluted electrode designs, which improve material utilization and transport processes, leading to higher power density, greater durability, and better fuel efficiency. Additionally, machine learning has shown potential in further optimizing these designs, allowing for the development of smaller, more cost-efficient PEMFC stacks with enhanced performance and fuel efficiency.

1.5.2. Solid alkaline fuel cell

Solid alkaline fuel cells (SAFCs) with anion exchange membranes (AEMs) have gained considerable attention in recent years, emerging as a key focus within renewable energy technologies. This is largely due to their high electrode activity, the potential to use non-precious metal catalysts, and relatively low fuel purity requirements. The AEM plays a pivotal role in these fuel cells, facilitating ion conduction, preventing fuel crossover, and supporting the catalysts. The efficiency and longevity of fuel cells are directly influenced by the performance of the AEM. Alkaline fuel cell technology, particularly anion exchange membrane fuel cells (AEMFCs), has been thoroughly researched. These fuel cells rely on an AEM to separate the anode and cathode chambers, allowing for the transport of alkaline anions, typically hydroxide ions (OH^-), between the electrodes. The development of polymer membranes capable of transporting hydroxide ions has been a notable advancement. Additionally, the crosslinking of anion-conducting materials with stable, steric ally-protected organic cations has proven to be an effective method for creating durable AEMs. This strategy enhances both the durability and performance of AEMs, improving the overall efficiency and lifespan of solid alkaline fuel cells. Research has also charted the development of anion-conducting membranes for these applications, shedding light on the evolution of this technology. Moreover, diagrams of alkaline anion exchange membrane fuel cells (AAEMFCs) have been provided to illustrate their operational principles [12].

1.5.3. Direct methanol fuel cell

Fuel cell is an application that converts chemical energy to electricity through chemical reactions that are distinct from burning. These are applied in various uses including the supply of power to residents and firms, and transportation of cars, buses, and trains. The majority of fuel cells operate on hydrogen which can be supplied directly to the fuel cell system or produced in the system by reforming hydrogen-rich fuel such as methanol, ethanol and hydrocarbon fuels. DMFCs use pure methanol, often dissolved in water and supplied to the anode of the fuel cell directly. A major advantage of direct methanol fuel cells is that some of the fuel storage issues unique to certain fuel cell systems, such as lack of energy density of hydrogen, are not typical of this type of fuel cell, though the density is lower than that of such fuels as gasoline or diesel. It is also easier to transport and supply using the current substructure because, like gasoline, methanol is a liquid substance. Thus, DMFC are employed for portable fuel cell applications Such as cell phones and laptop computers. There are some advantages of the fuel cells compared to the traditional combustion requiring technologies, or conversely, the main benefits include higher efficiency, zero or low emissions, and flexibility of fuels. Some can efficiently operate with power conversion capabilities in excess of 60% and deliver power to sizes ranging from a utility power plant to a laptop computer. Fuel cells are then compounded through research and development provided by NASA and private industry to be a substitute for the internal combustion engine, thereby altering the utility industry by making energy purer, cheaper, and portable. Washington is supporting the study of the hydrogen fuel cells to foster the generation of clean energy to support its cheapness in the future world energy market [13].

1.5.4. Phosphoric acid fuel cell

Phosphoric acid energy cells (PAFCs) represent the" foremost generation" of ultramodern energy cells and are one of the most constituted cell types commercially available. They use liquid phosphoric acid as an electrolyte, contained in a Teflon-clicked SiC matrix, and passable carbon electrodes containing's operation. PAFCs are generally used for inactive power generation, with some also being employed to power huge vehicles similar as megacity motorcars. They're known for their acceptance of contaminations in fossil energies changed into hydrogen, making them suitable for similar operations. Still, they're lower profitable at generating electricity alone compared to other energy cell types, with an effectiveness range of 37 – 42% [14]. When used for the co-generation of electricity and heat, Phosphoric acid energy cell can attain over 85 effectiveness, making them suitable for certain operations. Despite their benefits, PAFCs have limitations. They're less important, larger, and heavier compared to other energy cell types, and they bear advanced ladings of expensive platinum catalyst, making them fairly precious. Yet, they've set up operations in fixed power creators with affair in the 100 kW to 401 kW range and in larger vehicles similar as motorcars. PAFC technology has been developed and bettered significantly over the times, making it a good seeker for early stationary operations. Major a Pt. catalyst. The electrochemical responses that take place in the cells are pivotal for manufacturers of PAFC technology include Doosan Fuel Cell America Inc. and Fuji Electric. Also, PAFCs have been used for air-independent thrust in submarines.

1.5.5. Molten carbonate fuel cell

Molten carbonate fuel cells (MCFCs) are integrated advanced high temperature fuel cells suitable for power station, natural gas or coal fired plants, industries utilities and military usage. These cells exploit an electrolyte that is molten carbonate salts imbedded in a tough solid matrix of lithium aluminum oxide. These are functioning at around 650 centigrade (1150 Fahrenheit) temperate and MCFCs have the advantage of having non-precious metal both at the anode and the cathode. Indeed, MCFCs have some benefits that are clearly visible compared to the phosphoric acid fuel cells, such as better efficiency than PAFCs. Incorporation into a turbine system enables these cells to attain near 65 per cent efficiency, which is considerably higher than the 37 per cent to 42 per cent range apparent in PAFC systems. Furthermore, should the waste heat generated in the cell be utilized, then the general fuel efficiency is over 85 %. The MCFC technology is different from other types of fuel cells that include alkaline, phosphoric Acid and polymer electrolyte membrane fuel cells as they do not require an external reformer to develop fuel such as natural gas or biogas into hydrogen. Because of the high operating temperatures, it is possible to reform methane and other light hydrocarbons to hydrogen as a part of the overall cell internal reforming, which is cost effective. However, there are few drawbacks of using MCFC technology such as durability or long life. Operating temperatures are high, and electrolyte is usually corrosive thus degrading the cell components and shortening the overall life of the system. These are problems are being marked by researchers who are working day and night to come up with corrosion-resistant materials and make some small changes in the design of these cells in order to make these cells last longer by not compromising with efficiency[15].

Table: 1.2. Comparison of the fuel cells

Fuel cell Type	**Common electrolyte**	**Operating Temp. C^0**	**Efficiency %**	**Applications**
Polymer Electrolyte Membrane (PEM)	Ion Exchange membrane	50-100	40-50	Backup power Movable power Distributed Generation Transportation
Alkaline Fuel Cell (AFC)	Aqueous Solution of KOH	150-200	40-70	In Military In Space
Phosphoric acid fuel Cell (PAFC)	H_3PO_4	150-200	40-80	Distributed Generations
Molten Carbonate (MCFC)	Na_2CO_3 or $MgCO_3$	600-700	40-50	Electric use Distributed Generations
Solid oxide (SOFC)	YSZ	700-1000	60	Auxiliary power Electric use Distributed generation

1.5.6. Solid oxide fuel cell

1.5.6.1. History

Baur and Preis in 1937 gives the concept of SOFC by using ceramic material at 1000^0C different researchers in 1962 at Westinghouse worked on this cell by using zirconia oxide and calcium oxide. Now a days, in all over the world researchers worked on SOFC by using different materials as an electrodes and electrolyte to gain the maximum efficiency [16].

1.5.6.2. Characteristics of SOFCs

Strong oxide fuel cells (SOFCs) are a kind of cell which utilize a thick ceramic fabric as the electrolyte. These fuel cells work at greatly tall temperatures, around 1000°C, and can change over fuel into power with an effectiveness of around 60%. When arranged for co-generation, where squander warm is captured and reused, in general fuel proficiency can surpass 85% [17]. The tall temperatures dispense with the require for costly precious-metal catalysts, which makes a difference lower costs, and permit for inner fuel transforming. This implies SOFCs can handle an assortment of fills, counting common gas, biogas, and coal-derived gasses, without requiring an outside reformer. SOFCs too have the advantage of being safe to sulfur and unaffected by carbon monoxide, which makes them more flexible than numerous other fuel cell sorts. In any case, the tall working temperatures posture a few challenges. These incorporate slower startup times, the require for broad warm cover to hold warm and guarantee security, and the necessity for materials that can withstand the unforgiving conditions. The fundamental specialized jump is creating cost-effective materials that can persevere these tall temperatures. Research is underway to make lower-temperature SOFCs, working at or underneath 700°C, in trusts of tending to these solidness issues and cutting costs. Whereas this approach appears guarantee, lower-temperature SOFCs have however to coordinate the execution of their higher-temperature partners, and the look for appropriate materials proceeds.

1.5.6.3. Importance of SOFCs fuel cell

Different sorts of fuel cells have their claim benefits and downsides. Among them, (SOFCs) have picked up noteworthy consideration because of higher efficiency, cost-effectiveness, and the desire to use a different kinds of fills other than hydrogen, like hydrocarbons and coal gas Strong Oxide Fuel Cells SOFCs are a promising innovation for creating power for a wide extend of applications in the commercial segment.SOFCs offer several advantages over traditional procedures of power generation, including:

Tall productivity: SOFCs can accomplish efficiencies of up to 60%, which is essentially higher than routine strategies of control generation.

Fuel flexibility: SOFCs can utilize a run of fills, counting common gas, biogas, and hydrogen.

Low emanations: SOFCs deliver exceptionally more outflows, making them an ecologically neighbourly alternative for creating electricity.

Durability: SOFCs have a long life expectancy and can work for tens of thousands of hours without critical degradation.

Scalability: SOFCs can be used for numerous applications ranging from residential level systems, to distributed generation systems to large central power stations. Storing energy chemically as fuel and oxidant in a fuel cell involves conversion of the chemical energy of a fuel, hydrogen in most instances, and an oxidizing agent, oxygen in most instances, into electrical energy via an electrochemical process. Fuel cells comprise of three adjoining portions: The anode, the electrolyte, and the cathode. At the interfacing of the three different parts of a hybrid chemical system, there are two chemical reactions. The net outcome of the two responses is that fuel is exhausted, water or carbon dioxide is moulded another outcome is that an electrical current is delivered, which can be utilized to control electrical gadgets, regularly specified to as the stack [18].

Here is a step-by-step process of how fuel cells work:

1. Fuel, like hydrogen, is fed to the anode.

2. Oxygen or air is fed to the cathode.

3. Hydrogen molecules are split into electrons and protons at the anode.

4. The protons pass through the permeable electrolyte membrane, while the electrons are enforced through a circuit, generating an electric current and excess heat.

5. At cathode, oxygen combines with the electrons or protons to form water or carbon dioxide.

Like the name suggests, there is a solid oxide electrolyte in operation in the SOFCs. SOFCs are very favorable in medium and large power condition sectors. The current progress, as well as the future prospective of SOFCs, have been examined in the present review article by comparing the literature available over the last five years. Must of the existing review described a literature based on positions of certain SOFC constituents, namely anode, cathode and electrolyte Current advances and future standpoints of SOFCs have been discussed in the present review article by reviewing the literature over the last five years. Most of the existing review discussed the literature in positions of specific SOFC components, such as anode, cathode, and electrolytes. On the other hand, this review has reviewed the literatures in the province of two sorts of SOFC stack designs; linear and tube-like which are widely employed to integrate effective SOFC devices. Several studies have focused on the execution of a stack system for a novel design of SOFCs. The stack design is a crucial aspect of SOFCs, and it affects the performance, cost, and manufacturability of the device. The literature review outlined that one of the major used material sets of SOFCs is the flat-tubular design. This design combines the benefit of both planar and tubular SOFCs, resulting in a high-power output at low operating temperatures [19].

1.5.6.4. Design and operation of SOFC

SOFC are very differ than other types of the FCs. First of all their all parts (electrodes and electrolyte) are composed of solid material. Secondly these cells drive at high temperature but other FCs drive at low temperature. Solid state components of the SOFCs show that there is not fundamental restriction on the shape of cell. SOFCs categories into two main types, one is tabular cells or rolled tubes and flat -plates that's are applicable today in electronic industry. SOFCs consist of solid ceramic electrolyte (zirconia) which is present in between the anode and cathode Fuel is fed at anode while oxidant at cathode side. Fuel is oxidized at anode by losing the electron and oxidant reduce at cathode side by gaining electrons. The O_2 ion move toward the anode side by the porous electrolyte surface that maintained the overall electrical charge balance. There is an electrical connection in between the anode and cathode that's help in flow of the electron's anode to cathode pure water and heat are the byproduct in SOFCs these byproducts are used for co-generation purpose [20].

1.5.6.5. SOFCs reaction

Anode side reaction

$$H_2+O^{-2} \longrightarrow H_2O+2e^- \qquad (1)$$

$$CO+O^{-2} \longrightarrow CO_2+2e^- \qquad (2)$$

$$CH_4+4O^{-2} \longrightarrow 2H_2O+CO_2+8e^- \qquad (3)$$

Cathode side reaction

$$O_2+4e^- \longrightarrow 2O^{-2} \qquad (4)$$

There are three main components of FCs

Solid oxide fuel cell have three main constituents

Anode, Cathode and solid Electrolyte

Anode

Oxidation of fuel (H_2) takes place at anode surface in the presence of a catalyst.

Cathode

The cathode distributes the oxygen on surface comes from the air and conducts electrons from the circuit. After gaining electrons from the circuit the oxygen changed into oxygen ions which passed across the electrolyte and joined with hydrogen ions to form H_2O and heat as a byproduct.

Electrolyte

The electrolyte helps determine the operative temperatures of the cell and allows the charged ions to pass from itself to maintain the electrical charge balance. The electrolyte can also act as the oxygen ions and proton conductor. Flow diagram of SOFC is shown in fig 1.4.

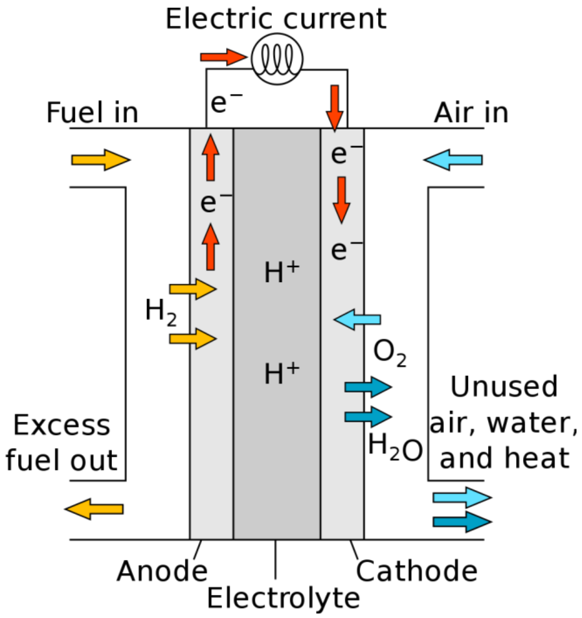


Fig 1.4 Hydrogen base SOFCs

1.5.6.6. SOFC components requirements

- Proper stability
- Proper conductivity
- Chemical compatibility with other components
- Electrolyte is dense that prevent the reactants mixing
- Porous electrode
- Higher toughness and strength properties
- Low cost components
- Operate at high temperature and not crack

Table 1.3 Material for SOFC

Electrolytes	Anodes	Cathodes	Interconnects	Seals	Rr
Zirconia Materials YSZ SSZ CaSZ **Ceria material** GDC SDC YDC CDC **La material** LSGM LSGMC LSGMF MSGMCF **Other material** YSTh YSHa BCY Bismuth oxide Based Ba and Sr Pyrochlor	**Nickel Material** Ni-O/YSZ Ni-o/SSZ Ni-O/SDC Ni-O/GDC **Copper Materials** CuO2/ CeO2/YSZ CuO2/YZT CuO2/YSZ CuO2/ CeO2/ SDC **Lanthanum Materials** LaSrCrO3 LST LaSrCrMO3 LAC **Other materials** TiO2/YSZ CeO2/YSZ Cobalt based Platinum based Ru/YSZ	Lanthanum Materials LSM and LSF LSC and LSCF LSMC and LSMCr LCM and LSCu LNF and LSFN LSCN and LBC LNC and LSAF LSFNCu and LSCNCu LNO **Gadolinium Materials** GSC GSM **Praseodymium Materials** PSM PCM PBC **Strontium materials** NSC and SSC BSCCu **Yttria materials** YCCF and YSCF YBCu	**Metals based Materials** Chromium Alloys Iron allays Ferritic stainless Steel Austenitic Stainless steel **Coatings** LCM LSM LSC LSFeCo LSCr LaCo3 **Ceramics** Lanthanum Chromites	Glass or glass Cermic Materials Mica-based composits	[21]

CHAPTER 2

LITERATURE REVIEW

Solid Oxide Energy Cells are a bright technology for polluted and effective energy product. One way to ameliorate their performance is by incorporating Sn answer in Ni/ YSZ as an anode catalyst, along with functional subcase deposited among the anode and electrolyte. Kan et al. (2010) demonstrated that Sn doping can achieve advanced temperature and power viscosity in SOFCs. By using methane gas (CH_4) as energy, the Sn- unravel Ni/ YSZ cell demonstrated an advanced power viscosity of $0.41Wcm^{-2}$ at 650^oC [22]. The Sn- unravel Ni/ YSZ cells also operated for a vastly longer period of 136 hours, compared to the Ni/ YSZ cell which operated for only 27 hours. These findings suggest that Sn doping is a serious factor in perfecting the performance of the SOFC, as it leads to the loftiest cell effectiveness. Farther exploration has also shown that Sn- unravel Ni/ YSZ catalysts have bettered dry reforming of biogas at SOFC operating conditions. Still, the electrochemical performance of the SOFC is veritably delicate to the volume of Sn unravel into the Ni/ YSZ anode, and repeated cell tests are necessary to optimize the Sn lading variation. In addition, strategies for carbon and sulphur tolerant SOFC accoutrements have been proposed, incorporating assignments from miscellaneous catalysis. These studies punctuate the significance of Sn answer in cultivating the performance and stability of SOFCs, and suggest that farther exploration is demanded to optimize the Sn lading and other factors to achieve indeed advanced effectiveness and continuity. To expand on the content of SOFCs, it's important to understand the background and environment of this technology. SOFCs are a type of energy cell that convert chemical energy directly into electrical energy, with high effectiveness and low- position radiations. They operate at high temperatures (generally800-1000^oC), which allow for the use of a variety of energies, including hydrogen, natural gas, and biogas. SOFCs have the eventuality to revise the energy assiduity by furnishing clean and dependable power for an expansive range of operations, from domestic and marketable structures to transportation and assiduity. Still, there are numerous tasks to overcome before SOFCs can come a conventional technology. One major challenge is the high cost of accoutrements and manufacturing, which limits the scalability and marketable viability of SOFCs. Another challenge is the continuity and trust ability of SOFCs, which can be affected by factors similar as thermal cycling, energy contaminations, and electrode degradation. To address these challenges, experimenters are exploring new accoutrements, designs, and manufacturing processes for SOFCs, as well as developing advanced individual and monitoring tools to ameliorate their performance and lifetime. Sn doping is critical aspect in perfecting the performance of SOFCs, as demonstrated by Kan et al. (2010) and other studies. Still, there are still numerous dares to overcome before SOFCs can come a mainstream technology, and farther exploration is demanded to optimize their effectiveness, continuity, and scalability [23].Morel et al. (2007) conducted a study on symmetrical LaO.8 SrO.2 MnO_3 (LSM) cells in a single chambered solid oxide energy cell (SC- SOFC) terrain to probe their catalytic exertion for different methane- to- oxygen rates. The experimenters examined the oxidation responses at electrode sintered at 1100°C and 1200°C and used electrochemical resistance spectroscopy (EIS) to track the effect of burning. The study set up that the catalytic exertion of the LSM electrode increased with temperature and the change in oxygen (O_2) species at temperatures above 700 °C could exceed 30 percent, leading to oxygen reduction and the emergence of low- frequency fractions in EIS spectra. The study also set up that the rise in sintering temperature dropped the catalytic exertion, and the LSM electrode performed more at 600°C than at 700°C. The study by Morel et al. (2007) provides precious perceptivity into the catalytic exertion of LSM electrodes in SC- SOFCs. The results suggest that the catalytic exertion of LSM electrodes is largely reliant on temperature and sintering conditions. The rise in temperature leads to an increase in catalytic exertion, but also to oxygen reduction and the emergence of low- frequency fractions in EIS spectra. This suggests that the optimal operating temperature for LSM electrodes in SC- SOFCs is around 600°C, where the catalytic exertion is high but the threat of oxygen reduction is minimized. The study also highlights the significance of sintering conditions in determining the catalytic exertion of LSM electrodes. The rise in sintering temperature decreases the catalytic exertion, which suggests that careful control of sintering conditions is essential to optimize the performance of LSM electrodes in SC- SOFCs. The use of EIS to track the effect of burning provides a precious tool for covering the performance of LSM electrodes in real- time, and could be used to optimize the operating conditions of SC- SOFCs. Overall, the study by Morel et al. (2007) provides important perceptivity into the catalytic exertion of LSM electrodes in SC- SOFCs, and highlights the need for farther exploration to optimize the performance of these electrodes. The use of advanced individual tools similar as EIS could help to develop the effectiveness and continuity of SC- SOFCs, and could pave the way for the expansive relinquishment of this promising technologyy [24].Resini et al. (2008) examined the performance of Ni- YSZ as a protagonist substantial for solid oxide energy cells (SOFCs) fueled by bioethanol. The study aimed to determine the optimal catalyst material for the anode face of SOFCs fueled by ethyl alcohol. The investigators set up that the addition of cobalt (Co) to the Ni- YSZ catalyst material redounded in the topmost performance. The recently synthesized Ni- Co/ YSZ catalyst material showed the loftiest performance among all the catalyst accoutrements tested. The study by Resini et al. (2008) provides precious perceptivity into the use of bioethanol as an energy for SOFCs and the optimal catalyst accoutrements for the anode face. The results recommend that the addition of cobalt to the Ni- YSZ catalyst material can significantly ameliorate the performance of SOFCs fueled by bioethanol. This finding has important counteraccusations for the development of more effective and supportable energy cell technologies. Farther exploration is asked to optimize the performance of SOFCs fueled by bioethanol and to explore the use of other renewable energies. The use of advanced individual tools similar as electrochemical impedance spectroscopy (EIS) could help to ameliorate the productivity and continuity of SOFCs, and could pave the way for the wide relinquishment of this promising technology. In addition, the hunt results give farther perceptivity into the use of catalysts for energy cell technologies, including the use of glycerol as a bio-syngas precursor via reforming route. The results suggest that the performance of catalysts can be bettered by enhancing size distribution and active phase dissipation. These findings punctuate the significance of catalyst accoutrements in energy cell technologies and the need for farther exploration to optimize their performance and continuity. Overall, the study by Resini et al. (2008) and the related hunt results give important perceptivity into the use of catalyst accoutrements for energy cell technologies and the need for farther exploration to optimize their performance and continuity. These findings have essential implications for the improvement of more efficient and sustainable energy technologies, and could help to pave the way for a cleaner and more sustainable future [25].Ye et al. (2008) audited the use of a catalyst subcaste (Cu- CeO_2) on the anode face for solid oxide energy cell (SOFC) fueled by ethanol. The study anticipated to determine the optimal catalyst material for the anode face of SOFCs fueled by ethanol. The experimenters set up that the circumstance of the catalyst material on the anode face redounded in an advanced power viscosity of $567 mWcm^{-2}$ at $800^{o}C$ operating on ethanol energy. The study also showed that the anode material could discharge for as long as 80 hours without carbon deposit, indicating long- term performance. The study by Ye et al. (2008) provides precious perceptivity into the use of catalyst accoutrements for SOFCs fueled by ethanol. The results suggest that the presence of a catalyst subcaste on the anode face can significantly ameliorate the performance of SOFCs fueled by ethanol. This finding has important counteraccusations for the development of more effective and sustainable energy cell technologies. Farther exploration is demanded to optimize the performance of SOFCs fueled by ethanol and to explore the use of other renewable energies. The hunt results give fresh perceptivity into the use of catalyst accoutrements for energy cell technologies, including the use of $NiCr_2O_3$- CeO_2NRs anode electro catalyst for ethanol electro oxidation response in alkaline media. The results suggest that the resistance to catalytically poisoning of $NiCr_2O_3$- CeO_2NRs is better among the synthesized catalysts. The evidence of a catalyst subcaste with unanticipated catalytic exertion for carbonous energies over the nickel- grounded anode has also been established as a factual way to ameliorate the performance of SOFCs. Determining the optimum subcaste fattiness, for the anode and cathode, is of topmost significance for minimizing the costs of the (DEFC). These findings punctuate the significance of catalyst accoutrements in energy cell technologies and the need for farther exploration to optimize their performance and continuity. In addition, the hunt results give perceptivity into strategies for C and S tolerant SOFC accoutrements, incorporating assignments from miscellaneous catalysis. These studies suggest that the actuality of a largely oxygen conductive phase in the anode authorities a certain degree of electrochemical oxidation of sulfur to grease sulfur junking. These findings have important consequences for the development of further durable and reliable SOFCs that can operate on a wide range of energies. Overall, the study by Ye et al. (2008) and the related hunt results give important perceptivity into the use of catalyst accoutrements for energy cell technologies and the need for farther exploration to optimize their performance and continuity. These findings have important counteraccusations for the growth of more effective energy technologies, and could help to pave the way for a cleanser and redundant sustainable [26]. Ullah et al. (2018) delved the use of rare earth essence, including samarium(Sm), cerium, and gadolinium (Gd), in the electrolyte and catalyst accoutrements of (SOFCs). The study anticipated to determine the optimal catalyst material for the anode face of SOFCs fueled by ethanol. The experimenters set up that the use oftri-doped (M = Sm, Ca, Gd) ceria $MO.2CeO.8O_2$- δ as an electrolyte redounded in a lower functional temperature compared to conventional electrolytes. The electrical conductivity of the set samples was measured using a Probo- Stat-NorECs setup, which showed a conductivity of 1.2×10^{-2} Scm^{-1} at 700°C. Raman and UV-visible spectroscopy were used to characterize the set samples, to check the absorbance and molecular climate. The crystal clear structure was measured by x-ray diffraction, which showed that the dopants were effectively unravel in CeO_2. The set samples handed a power viscosity of 314 mW cm^{-2} by using ethanol energy at 550 °C. The study by Ullah et al. (2018) provides appreciated perceptivity into the use of rare earth essence in SOFC and the optimal catalyst accoutrements for anode face. The results recommend that the use oftri-doped ceria as an electrolyte can significantly ameliorate the performance of SOFCs fueled by ethanol. This finding has important counteraccusations for the development of more effective and sustainable energy cell technologies. Farther exploration is demanded to ameliorate the performance of SOFCs fueled by ethanol and to explore the use of other renewable energies. The hunt results give fresh perceptivity into use of rare earth essence in energy cell technologies, including their use in the product of high- performance attractions, blends, spectacles, and electronics. The results suggest that rare earth essence similar as cerium, lanthanum, and neodymium are important catalysts for petroleum refining and as diesel complements. The use of rare earth essence in the product of energy cells and nickel- essence hydride batteries has also been demonstrated as an effective way to ameliorate the performance of SOFCs. These findings punctuate the significance of rare earth essence in energy cell technologies and the need for farther exploration to optimize their performance and continuity. In addition, the hunt results deliver perceptivity into the cornucopia and uses of rare earth essence in ultramodern technologies and life. The results suggest that rare earth essence are used in a wide variety of operations, including the defenses of smartphones, computers, and other bias, automotive catalytic transformers, attractions, and sword timber. These findings have important counteraccusations for the sustainability and environmental impact of ultramodern technologies, and could help to inform programs and practices aimed at reducing the use of non-renewable coffers. Overall, the study by Ullah et al. (2018) and the related hunt results give important perceptivity into the use of rare earth essence in energy cell technologies and the need for farther exploration to optimize their performance and continuity. These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to cover the way for a cleaner and further sustainable futuree [27].Mushtaq et al. (2018) studied the use of Ti- unravel $SrFeO_3$ as a cathode material for solid oxide cells (SOFCs). The study aimed to determine the optimal cathode material for SOFCs operating at low temperature. The experimenters set up that the use of Ti- unravel $SrFeO_3$ as a cathode material redounded in maximum performance at low temperatures. The cathode material was prepared using the sol- gel system, and its structure, morphology, and thermo gravimetric characteristics were delved using different ways. The boxy perovskite structure of the cathode was verified byx-ray diffraction. The electrical conductivity the set samples was measured using the four-inquiry system, which showed a conductivity of 1.2×10^{-2} Scm^{-1} at 700°C. The equipped cathode material gave a power viscosity of 551 mW cm^{-2} at 600°C when using ethanol energy. The study by Mushtaq et al. (2018) provides precious perceptivity into the use of Ti- unravel $SrFeO_3$ cathode material for SOFCs operating at low temperatures. The results suggest that the use of Ti- unravel $SrFeO_3$ as a cathode material can deliberately expand the performance of SOFCs operating at low temperatures. This finding has important counteraccusations for the development of more effective and sustainable energy cell technologies. Farther exploration is demanded to ameliorate the performance of SOFCs operating at low temperatures and to explore the use of other renewable energies. The hunt results give fresh perceptivity into the use of different accoutrements for energy cell technologies, including the use of rare earth essence, similar as cerium, lanthanum, and neodymium, as catalysts for petroleum refining and as diesel complements. The use of different deposit styles for oxides, similar as stabilized zirconia, has also been established as an effective way to ameliorate the performance of SOFCs. These findings punctuate the significance of accoutrements in energy cell technologies and the need for farther exploration to optimize their performance and continuity. In addition, the hunt results give perceptivity into the medication and characterization of solid electrolytes for energy cell operations. The results suggest that the sol- gel system is a useful fashion for the grounding of spectacles and thin film samples, and that the use of different deposit styles can significantly ameliorate the performance of energy cells. These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to pave the way for a cleaner and further sustainable future. The study by Mushtaq et al. (2018) and the related hunt results give important perceptivity into the use of different accoutrements for energy cell technologies and the need for farther exploration to optimize their performance and durability. These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to cover the way for a cleaner and further sustainable future [28].Ali et al. (2018) delved the use of LNK- SDC electrolyte and LNCZFO electrode accoutrements for direct carbon energy cells (DCFCs). The study aimed to determine the optimal accoutrements for DCFCs that could use different carbonaceous energies, similar as carbon, carbon filaments, graphite, lignite, bituminous coal, watercolor, and other redundant accoutrements, to convert their chemical energy into electrical energy. The electrolyte material was synthesized using theco-precipitation system, and the electrode material was prepared using the solid- phase response system. The boxy crystalline structure of the material was verified using x-ray diffraction. The electrical conductivity of the set samples was measured using the four- inquiry system, which showed an ionic conductivity of 0.0998 $Scm^{-1}$for the electrolyte (LNK- SDC) and an electronic conductivity of 10.1 $Scm^{-1}$for the electrode (LNCZFO) at 700°C. The set accoutrements handed a power viscosity of 58 $mWcm^{-2}$ when using sub-bituminous energy. The study by Ali et al. (2018) provides precious perceptivity into the use of LNK- SDC electrolyte and LNCZFO electrode accoutrements for DCFCs that can use different carbonaceous energies. The results propose that the use of these accoutrements can significantly ameliorate the prosecution of DCFCs and enable the conversion of a wide range of carbonaceous energies into electrical energy. This finding has important counteraccusations for the development of further emotional and sustainable energy cell technologies. Farther exploration is demanded to enhance the performance of DCFCs and to explore the use of other renewable energies. The hunt results give fresh perceptivity into the use of different material for energy cell technologies, including the use of molten carbonate electrolytes and ceria- grounded compound electrolytes. The results suggest that the use of different deposit styles for oxides, similar as stabilized zirconia, has also been established as an operative way to ameliorate the performance of SOFCs. These findings punctuate the significance of accoutrements in energy cell technologies and the need for farther exploration to optimize their performance and durability. In addition, the hunt results give perceptivity into the operating characteristics of DCFCs completed of different construction accoutrements, similar as carbon sword, pristine sword, and nickel. The results propose that the use of different construction accoutrements can significantly affect the vacuity and continuity of DCFCs, and that the selection of applicable accoutrements is critical for the successful operation of DCFCs. These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to pave the way for a cleaner and further sustainable future. Overall, the study by Ali et al. (2018) and the related hunt results give important perceptivity into the use of different accoutrements for DCFCs and the need for farther exploration to optimize their performance and continuity. These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to cover the way for a cleaner and further sustainable future. Doped- $SrTiO_3$ is a type of anode material that has gained attention due to its excellent stability under both oxidizing and reducing conditions, reasonable thermal expansion, and high forbearance to sulfur and carbon deposit. also, strontium Titanates are chemically well- suited with the most considerably used solid electrolytes Zr0.82Y0.16O1.92(YSZ), La0.8Sr0.1Ga0.8Mg0.2O_3- δ(LSGM), and Ce 0.9 Gd 0.1O 1.95(CGO). Still, the performance of strontium Titanates is rather modest compared to the state- of- the- art anode accoutrements due to their deprived ionic conductivity and electro catalytic exertion [29].The performance optimization of $SrTiO_3$-based anode materials has recently garnered attention. For instance, one article published on Research Gate deals with the creation of an anode material in the form of lanthanum-substituted strontium titanate perovskite doped with manganese and gallium for the application in Solid Oxide Fuel Cells. It was found that the perovskite structure is thermally stable in both oxidizing and reducing environments and maximum power density is obtained for anode composed of both manganese and gallium doped material. Another research also described the performance of NiO-doped $SrTiO_3$ (Ni-STN) and its application as an anode material for SOFCs claiming redox stability. The role of the Ni-STN material was found to enhance catalytic activity and stability during redox cycles. Although $SrTiO_3$-based anode materials possess some interesting properties, their performance level still needs further enhancement to be suitable for SOFC anode applications. There is a positive trend in research focused on enhancing the performance of these materials, however, further research work is required to achieve the maximum efficiency of the materials in application. Recently, Nano composite materials have gained considerable attention for increasing the electrochemical activities of conventional air electrodes with the combination of Ce0.9Gd0.1O1.94 (CGO) for example La0.8Sr0.2MnO$_3$-δ (LSM) and La0.5Sr0.4Co0.2Fe0.8O$_3$-δ (LSCF). In high-temperature sintering processes, the introduction of CGO aids in decreasing the formation of pores, leading to the development of Nano composite electrodes with a higher number of active regions for the ORR. For instance, $LaCrO_3$-CeO_2 Nano composites were treated as symmetric electrodes, which exhibited exceptional performances with 0.29 and 0.09 Ω cm^2 for polarization resistance at temperatures of 750°C when placed in the atmosphere and hydrogen respectively. The improvement of the hydrogen performance has been related to the remarkable characteristics of nanostructured electrodes and the nano-CeO_2 which is also a good catalyst for many electro catalytic processes. To improve the electrochemical properties of air electrodes of SOFCs, it was possible to propose new Nano composite electrodes which can be obtained by Pr-doped $SrTiO_{3\pm\delta}$ and CGO, these electrodes are said to have high redox stability and improved performance for both oxygen reduction reaction (ORR) and hydrogen oxidation reaction (HOR) in symmetric SOFCs. The Nano composite electrodes in this case would have smaller grains owing to inhibition of pore development providing more active spots for ORR and HOR for enhanced effective activity. This particular method could allow for the fabrication of more efficient and stable air electrodes for the SOFCs. All in all, the combination of Nano composite materials shows a bright outlook for the enhancement of air electrodes in SOFCs. The combination of Pr doped $SrTiO_3$±δ and CGO will give rise to new electrodes that will have high redox stability and thus better performance hence moving towards the production of advanced and more stable SOFCs with the prospects of being useful in clean energy technologies. A more recent literature review addresses the application of the different biofuels (liquid, e.g. pyrolytic oils, alchohol, biodiesel, solid – bio char, gaseous syngas and biogas) in IT-SOFCs, also matching biofuels regions to materials for electrodes and electrolytes that target SOFC use with oxygenated biofuels at the intermediate temperatures. The review, for its part, seeks to advance the theory by explaining some of the more competing electrochemical processes that ensue in the anode when biofuels are directly fed. Attempts are made to qualitatively explain the electrochemical processes that take place in IT-SOFCs using oxygenated biofuels, by looking typically at the chemistry at the anode. This model is further extended to IT-SOFCs operating on methanol and it analyzes the causes of poor performance of these fuel cells having biofuels. The review encompasses progress in materials and techniques for SOFC operation in reduced temperatures that are achieved through advancement of anode, electrolyte and cathode materials to operate SOFCs below 600^0C Further it highlights the basics of SOFC, selection of electrolytes materials and fabrication of materials inside SOFCs. The review also looks at the questions related to design and operational characteristics of energy cells, including electrodes in SOFCs which determine the performance [30].Bilayer Y_2O_3-stabilized ZrO_2(YSZ)/ Sm_2O_3- unravel CeO_2(SDC) electrolyte flicks were appreciatively made- up on pervious NiO – YSZ emulsion face using electrophoretic deposit(EPD) followed byco-firings with the substrates. In the EPD process, appreciatively charged YSZ and SDC maquillages were deposited straight on the face, subcaste by subcaste from ethanol- grounded dormancies. Delamination between YSZ and SDC flicks was avoided by reducing the SDC flicks' consistence to roughly 1 μm. A single cell was made on the bilayered electrolyte flicks composed of roughly 4.0 μm-thick YSZ and roughly 1.0 μm-thick SDC flicks. La 0.6 Sr 0.4 Co 0.2 Fe 0.8 O_3 − x (LSCF) was used as the cathode in the cell, and maximum affair power consistence lesser than 0.6 W cm^{-2} were attained at 700 °C for the bilayered YSZ/ SDC electrolyte cells therefore constructed (31).A promising material for use in the anode cube of solid oxide energy cells (SOFCs) operating at 650 °C is A-site lacking strontium Titanate-La 0.2 Sr 0.7 TiO_3. This material can be reduced at high temperatures (1000°C) and shows sufficient conductivity, enhanced energy oxidation, and bettered current collection parcels through impregnation with active accoutrements. Button cells were fabricated, conforming of a passable frame of this electronically conductive material saturated with CGO and Cu as the energy electrode, and YSZ as the electrolyte, to test the energy cell performance. Morales M, Espiell F, Segarra M.Anode- supported single- chambered solid oxide energy cell(SOFCs) were studied with NiGDC/ GDC/ LSC- GDC, with and without Cu – ZnO – Al_2O_3 catalyst layers on the anode face, worked on ethanol and air fusions. The optimal operating circonstance were determined at a cell temperature of 450°C, an ethanol- air molar rate of 0.44, and a total gas inflow rate of $400mlmin^{-1}$. Also, the cells should be concerned with perpendicularly to the gas inflow direction with the cathode exposed to the fresh gas. Recent exploration has concentrated on anode- supported SOFCs, similar as those with Ni- YSZ/ YSZ/ GDC/ LSC, which are suitable for intermediate temperature(below 800°C) SOFC exploration and development. Anode- supported single- chamber SOFCs have also been studied in air fusions, using YSZ solid electrolyte with a Nikel anode and LSM cathode. Likewise, the catalytic exertion of Platinum and Nikel-grounded anodes for the deficient oxidation of methane has been investigated. Anode-supported SOFCs grounded on Gd- unravel ceria(GDC) electrolyte and NiO- GDC anode have been made- up by the gel- casting system for direct- methane operation under catalytic partial oxidation(CPOX) conditions. The study demonstrated the good stability of Ni- GDC anode and support under CH_4/ air as energy, indicating its eventuality for championing the internal catalytic reforming of methane towards CPOX .Kan H, Lee H. Tin-doped Ni/YSZ was employed as an anode activator for the fabrication of single SOFC cells. To achieve high power density at intermediate temperatures, a functional layer was added between the majority anode and the electrolyte. The performance and stability of single cells with the same microstructure were compared for Nikel/YSZ and Sn-doped Nikel/YSZ anodes. Key findings include, Similar power densities were obtained for Ni/YSZ and Tin-doped Ni/YSZ single cells (0.39 W cm^{-2} vs. 0.41 W cm^{-2}), indicating comparable performance Sn-doped Ni/YSZ demonstrated enhanced long-term stability (27 h vs. 137 h), which can be attributed to a lower rate of deposition of amorphous carbon. The stability of the Tin-doped Ni/YSZ cell was further improved when carbon deposited on the surface during operation was removed. These results highlight the potential of Tin-doped Ni/YSZ anode catalysts in intermediate temperature SOFCs, offering enhanced carbon deposition resistance and long-term stability [32].Ye XF, Wang SR, Wang ZR, Xiong L, Sun XF, Wen TL.Anode- supported SOFCs rested Gd- unravel ceria (GDC) electrolyte and NiO-GDC anode support have been made- up by the gel- casting system for direct- methane operation under catalytic partial oxidation (CPOX) conditions. Also, progress has been reported on the use of conductive anode catalysts, analogous as LiLaNi- Al_2O_3 and bull, in SOFCs for methane internal perfecting and partial oxidation [33].Energy is a vital factor for the profitable progress of a country. Pakistan, like multitudinous other underdeveloped countries, relies simply on conventional archconservative powers to meet its energy conditions. Due to its enormous population and recent artificial development, there is a vast demand for energy. Still, archconservative energy prices have enlarged recently, and the country has no other means to produce energy, performing in energy faults. The electricity demand and force gap has increased extremely, and all sectors of life have been severely affected. Policy makers worldwide are looking for alternate ways of energy to break energy failure problems.

Different sources of alternate and renewable energy are being explored in Pakistan as well. Solar and wind energy sources have been compared predicated on price, average life span, emigration of dangerous feasts, ingesting of energy, operation, and conservation charges. Solar energy has surfaced as the swish source of renewable energy to attack all the energy challenges as it's cheaper, does n't bear operation or conservation costs, and has a better average life span than wind energy [34].Renewable energy sources, analogous as solar and wind, are naturally refilled and don't run out. They can be used for electricity generation, space and water heating and cooling, and passage. In Pakistan, where 60 of electricity is generated through precious imported archconservative powers and coal, there is a dire need for affordable electricity and environmental protection. The country has set ambitious targets to increase the share of renewable energy in the public power grid from 5 to 20 in 2025 and to 30 in 2030. Solar energy, in particular, has surfaced as an attractive alternate energy result for the common millions in Pakistan, with the eventuality to meet the country's current electricity demand [35]. Research in the field of SOFCs has focused on enhancing coking resistance to improve the performance and resilience of the cells, particularly when using carbon-containing fuels. Various studies have demonstrated the effectiveness of different catalysts and materials in mitigating the impact of carbon deposition on the anodes of SOFCs. These advancements are crucial for the practical application of SOFCs in energy conversion from an extensive range of fuel sources, including methane, biogas, and ethanol [36]. The development of well-organized and stable photo catalysts for environmental remediation applications has been a subject of intense research. The use of quantum dots, such as copper sulfide, has shown great potential in enhancing the photo catalytic activity of TiO_2 nanotubes. The resulting composites have been evaluated for the photo degradation of organic dyes, such as malachite green and phenol, with promising results [37].The study's findings emphasize the eventuality of conductive polymer binders in enhancing the performance of lithium- ion battery anodes, particularly those grounded on silicon. By reining the electrical conductivity of the anode and adding the active material content, the exploration contributes to the ongoing sweats to optimize the capacity parcels of Li- ion batteries. These advancements are pivotal for the practical operation of lithium-ion batteries in colorful energy storehouse and conversion systems, including electric motorcars and grid- scale energy storehouse [38]. The anode- supported SOFC with a NiO- YSZ anode, YSZ electrolyte, and GDC- LSM|| LSM complex cathodes displayed excellent chemical stability, firm cell structure, and promising electrochemical performance. The continuity evaluation demonstrated the cell's capability to repel long- term operation and thermal cycles, making it a feasible seeker for practical SOFC applications. The new synthetic route enabled the successful conflation of Ln2/ 3 − $xTiO_3{}^{-3}$ x/ 2(Ln = La, Pr, and Nd) composites with enhanced densification. The optimized precursor medication and the sol – gel system proved to be effective for utmost lanthanide compositions, except for cerium. The electrical characterization of La- and Pr- grounded LTOs revealed their eventuality for colorful operations taking effective charge transport parcels [39]. The new synthetic route enabled the successful conflation of Ln2/ 3 − $xTiO_3{}^{-3}$ x/ 2(Ln = La, Pr, and Nd) composites with enhanced densification. The optimized precursor medication and the sol – gel system proved to be effective for utmost lanthanide compositions, except for cerium. The electrical characterization of La- and Pr- grounded LTOs revealed their eventuality for colorful operations taking effective charge transport parcels [40]. The citric acid–nitrate process was successfully employed to synthesize LSTC materials with a single-phase perovskite structure and outstanding chemical compatibility with YSZ. The chromium doping up to 20 mol% did not disrupt the perovskite structure. The LSTC powders exhibited a nanoparticle size distribution, and the sintered pellets showed a highly densified microstructure. These results suggest that LSTC is a capable candidate material for SOFC applications, particularly as a cathode or interconnect material [41]. This study demonstrates the promising electrochemical performance of LSFNT-based anodes for SOFC applications. The anode compositions exhibited high peak power densities and fuel utilization, making them attractive alternatives to conventional Ni: YSZ composite electrodes. The redox stability and corrosion resistance of LSFNT-based anodes offer a significant advantage over traditional anode materials, pavement the way for the development of more efficient and durable SOFC [42]. Efficient and stable operation of MS-SOFCs relies on the development of LSM/8YSZ cathodes that can be formed without high-temperature sintering processes. By focusing on the interfacial properties between the cathode, electrolyte, and composite phases, researchers can optimize the electrochemical behavior of the cell, leading to improved performance and long-term stability. This approach is crucial for advancing the development of MS-SOFCs with enhanced efficiency and durability [38]. Metal-supported SOFs (MSCs) have emerged as an attractive alternative to conventional anode-supported cells (ASCs) for various applications, particularly in the field of mobile auxiliary power units (APUs), MSCs offer several advantages, such as lower production costs and improved ruggedness, making them suitable for harsh operating conditions. However, the use of metallic substrates necessitates specific adaptations to the SOFC processing technologies to avoid oxidation during high-temperature sintering under oxidizing atmospheres. The thin metal-supported SOFC developed in this study shows promise for mobile or portable applications due to its enhanced mechanical flexibility and durability. The successful fabrication and characterization of this cell demonstrate the potential of this design for improving the overall performance and consistency of SOFCs [43].The strong correspondence of both electrode materials and simplicity of construction of the cell are very important for the further development of (SOFC) technology.gy. In this work, bi-functional hybrid material, LaNi0.82Fe0.17O_2 (LNF)/NiO was prepared by a one-pot citrate method and used as quasi-symmetrical electrode catalysts of SOFCs. The LNF and Ni (reduced NiO) components behaved as cathodic and anodic electrodes' catalysts, respectively. Further, LSGM based asymmetrical tri-layered substrates were prepared with a screen-printing assisted co-firing technique [44].PSFNM perovskite doped with molybdenum were synthesized by an improved Pechini technique and employed as both anode and cathode in intermediate temperature SSOFCs. In the theoretical aspect, the study aim to explore the impact of Mo-doping on the following properties of Pr0.6Sr0.4Fe0.8Ni0.2$O_{3-\delta}$ (PSFN) electrodes: the structural change, electrical conductivity, coefficient of thermal expansion and electrochemical performance [45]. The integration of the SFM predecessor solution into a three-ply LSGM support structure made it possible to produce SFM/LSGM bipolar fuel cells and also practical fuel cells on an ultra-rapid and efficient basis. The choice of cell structure in terms of geometries has favored high TSHR and the good match of the TEC between the SFM and the LSGM to steadfast the structural stability of the fuel cells. The small difference in polarization resistance of the SFM/LSGM composite electrodes suggest the great electrochemical activity of these bipolar fuel cell structures [46].

CHAPTER 3

MATERIAL AND METHOD

3.1. Synthesis

3.1 Sol gel method

The sol-gel technique is a very extended well-known since the late 1800s [47]. The sol-gel is a wet chemical method use to fabricate thin film, powder, or fibers. Molecular precursors are dissolved in H_2O or ROH and changed into a gel by heating or stirring the raw materials. Material thus developed will be dried using a suitable method, various methods have been represented in literature examples oven dry, air dry.The sol-gel method is a widely used technique for the preparation of many materials, including perovskite anode materials. The method involves dissolving molecular ancestors in water or alcohol and converting them into a gel by heating or stirring the raw materials. The resulting gel is then dried to form a powder or film. The sol-gel method is an inexpensive and low-temperature technique that permission for the fine control of the product's chemical composition. The sol-gel method can be used to prepare perovskite catalysts, membranes, and powders, among other materials. For example, the Sol-Gel Pechini method is an adaptable procedure for preparing perovskite membranes. The method involves chelate poly esterification and is commonly used for depositing dielectric coatings. However, the method is very sensitive to moisture and can be difficult to scale up. It can also include several steps and is a time-consuming process. The sol-gel formation of perovskite by an EDTA/citrate complexing method contains Nano scale solid-state reactions. The method permits for the precise control of the product's chemical composition and the formation of phase-pure products. Double perovskite Sr_2FeMoO_6 can be prepared by the sol-gel technique and solid-state reaction method. The resulting dusts from gel and solid-state reaction methods were characterized and compared. The sol-gel method was found to produce a more homogeneous product. A layered double perovskite oxide with A-site ordered layered structure can be prepared via a sol-gel method and studied as the DC-SOFC anode material. The method involves dissolving molecular precursors in water or ROH and converting them into a gel by heating or stirring the raw materials. The resulting gel is then dried to form a powder or film [48].

Fig.3.1. Gel obtained at 80C^0 continuous Heating and stirring 4 hours

3.2. Preparation ($LaSrCuTiO_{3-0}$) by wet chemical technique

LaCuTiO powers as anode for SOFC were prepared by sol get way. The stoichiometric amount of,

Lanthanum hex nitrate La $(NO_3)_3$ $6H_2O$ (sigma Aldrich 99.99%)

Strontium nitrate Sr $(NO_3)_2$

Copper (II) nitrate trihydrate $Cu(NO_3)_2.3H_2O$(Glenthan)

Titanium (IV) oxide TiO_2 (riedel-detlaen)

Were used in this synthesis.an appropriate molar ratio of strontium nitrate Lanthanum hex nitrate $La(NO_3)_3.6H_2O$ and Copper(II) nitrate trihydrate $Cu(NO_3)_2.3H_2O$ dissolved into 150ml distilled water and heat at 120^o C in a hot magnetic stirrer. Titanium (IV) oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^o C through the hot magnetic stirrer. After heating and stirring TiO_2 solution at 120^o C for half hour, add it into $La(NO_3)_3$. $6H_2O$, and $Cu(NO_3)_2$ H_2O solution. Citric acid was added 20% of the total moles of LCuT into solution. After that, this overall solution was heated continuously at temperature 120^o C for 8h to obtain gel. The obtaining gel was dry at 120^o C for four hours in an oven and crushed in mortar pestle to achieve powder. Then followed by calcination at temperature 1000^o C for five hours. Finally, the fine powder were grounded and ready for characterization.In this way total four samples were prepared with different concentrations, these samples were,

Sample F_1

4.3301g Lanthanum hex nitrate $La(NO_3)_3.6H_2O$ and 0.966g copper nitrate trihydrate $Cu(NO_3)_2$. $3H_2O$ dissolved into 150ml distilled water than heat and stir at 120^o C, Titanium oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add 1.437g of TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^o C.After heating and stirring TiO_2 solution, add it into the previous solution. Citric acid was added 20% (2g) of total moles of $LaCuTiO_{3.0}$ into solution. After that, this overall solution was heated continuously at temperature 120^o C for 8h to attain gel. The gel was dried at 120^o C for four hours in an oven and crushed in mortar pestle to attain powder. Then followed by calcination at temperature 1000^{o} C for five hours. Finally, the fine powder was grounded and this sample F_1 was ready for characterization.

Fig 3.2. Solution of Lanthanum hex nitrate, Strontium nitrate, Copper nitrate and Titanium oxide heat and stir about 120C^{0}

Sample F_2

4.3301g Lanthanum hex nitrate $La(NO_3)_{3.}$ $6H_2O$ and 0.193g copper nitrate trihydrate $Cu(NO_3)_{2.}$ $3H_2O$ dissolved into 150ml distilled water than heat and stir at 120^{o} C, Titanium oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add 1.437g of TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^{o} C. After heating and stirring TiO_2 solution, add it into the previous solution. Citric acid was added 20% (2g) of total moles of $LaCuTiO_{3.0}$ into solution. After that, this overall solution was heated continuously at temperature 120^{o} C for 8h to attain gel. The gel was dried at 120^{o} C for four hours in an oven and crushed in mortar pestle to attain powder. Then followed by calcination at temperature 1000^{o} C for five hours. Finally, the fine powder was grounded and this sample F_2 was ready for characterization.

Sample F_3

4.3301g Lanthanum hex nitrate $La(NO_3)_{3.}$ $6H_2O$ and 0.289g copper nitrate trihydrate $Cu(NO_3)_{2.}$ $3H_2O$ dissolved into 150ml distilled water than heat and stir at 120^o C, Titanium oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add 1.437g of TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^o C.After heating and stirring TiO_2 solution, add it into the previous solution. Citric acid was added 20% (2g) of total moles of $LaCuTiO_{3.0}$ into solution. After that, this overall solution was heated continuously at temperature 120^o C for 8h to attain gel. The gel was dried at 120^o C for four hours in an oven and crushed in mortar pestle to attain powder. Then followed by calcination at temperature 1000^o C for five hours. Finally, the fine powder was grounded and this sample F_3 was ready for characterization.

Sample F_4

4.3301g Lanthanum hex nitrate $La(NO_3)_{3.}$ $6H_2O$ and 0.386g copper nitrate trihydrate $Cu(NO_3)_{2.}$ $3H_2O$ dissolved into 150ml distilled water than heat and stir at 120^o C, Titanium oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add 1.437g of TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^o C.After heating and stirring TiO_2 solution, add it into the previous solution. Citric acid was added 20% (2g) of total moles of $LaCuTiO_{3.0}$ into solution. After that, this overall solution was heated continuously at temperature 120^o C for 8h to attain gel. The gel was dried at 120^o C for four hours in an oven and crushed in mortar pestle to attain powder. Then followed by calcination at temperature 1000^o C for five hours. Finally, the fine powder was grounded and this sample F_4 was ready for characterization.These four samples were used in SOFC as anode material for to improve its conductivity.

Fig 3.3: Powder form sample obtained after dry and Sintering at 900^0C

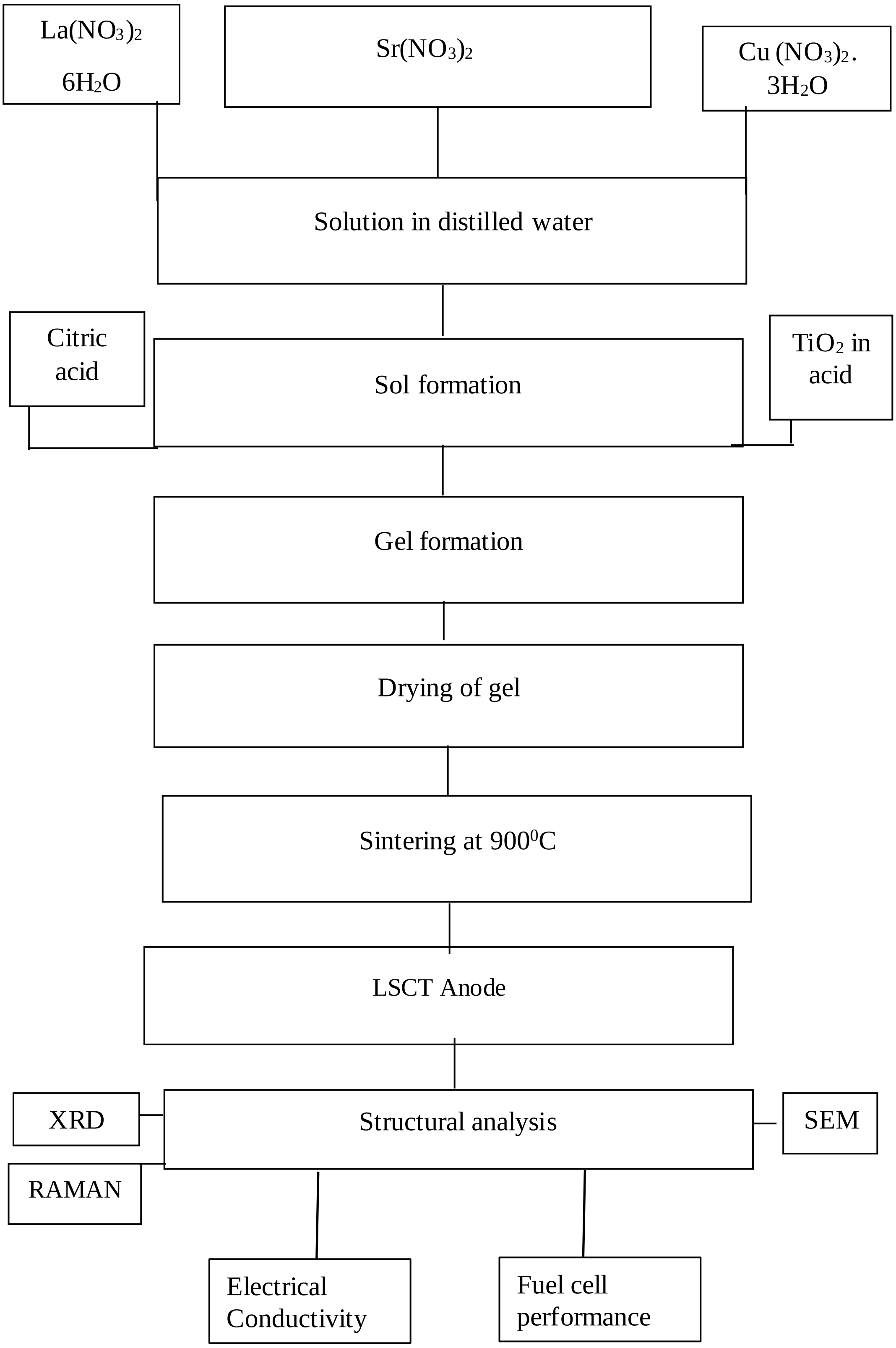


Fig 3.4: Flow diagram for anode synthesis

3.3: Characterization

3.3.1: Scanning Electron Microscope (SEM)

Scanning electron microscopy (SEM) is a technical electron microscope that employs a focused ray of electrons to overlook the face of a sample, generating signals that carry information about the face and composition of the substance. The electron ray is scrutinized in a conformation pattern, and the position of the ray is combined with the strength of the detected signals to produce an image. In a standard SEM setup, the electron ray is released from an electron gun featuring a tungsten hair cathode. SEM drivers can magnify their images up to 1- 2 million times. Generally, SEM operates with acceleration voltages of over to 30kV, furnishing a three- dimensional representation of the sample's face [49].

3.4.2: X- ray diffraction (XRD)

X-ray diffraction (XRD) is a system that utilizes X-ray shafts of a specific wavelength to interact with material patches. These shafts are dispersed depending on the crystal clear structure of the sample, creating a plot of intensity as a function of 2 theta. XRD provides information about the liquid structure of nanoparticles, as well as the unformed, crystalline, and ordered- disordered molecular arrangement parcels of the material. It also offers details on crystallography, including the crystal-clear structure of the sample, chassis parameters from the peaks, phases produced due to material processing, and the flyspeck size of the sample X-ray crystallography is a scientific system used to find out the medication of tittles of a crystalline solid in three-dimensional space. This system takes advantage of the interatomic distance of utmost liquid solids by engaging X-rays, which have wavelengths on the order of 1 angstrom (10- 8 cm). X-ray crystallography remains the primary tool used by experimenters in characterizing the infinitesimal structure of new accoutrements [50].

3.4.3: Conductivity Measurement

The four- point inquiry fashion is an extensively employed system for determining the electrical conductivity and resistivity of accoutrements. This approach involves the operation of a current through two external examinations and the dimension of the voltage across the inner examinations. The setup consists of four examinations arranged linearly in a straight line at equal distances from each other, with a sample deposited between them [51].

CHAPTER 4

RESULTS

4.1. UV Spectrum

The wavelength where absorption starts to increase sharply corresponds to the material's band gap. If LSC-TiO has an onset around 350 nm, it suggests a band gap of approximately 2.75 eV (using the relationship Eg=1240λonsetE_ {g} = \frac{1240}{\lambda_{onset}}Eg=λonset 1240ineV,whereλonset\lambda_{onset}λonset is the onset wavelength in nm

1

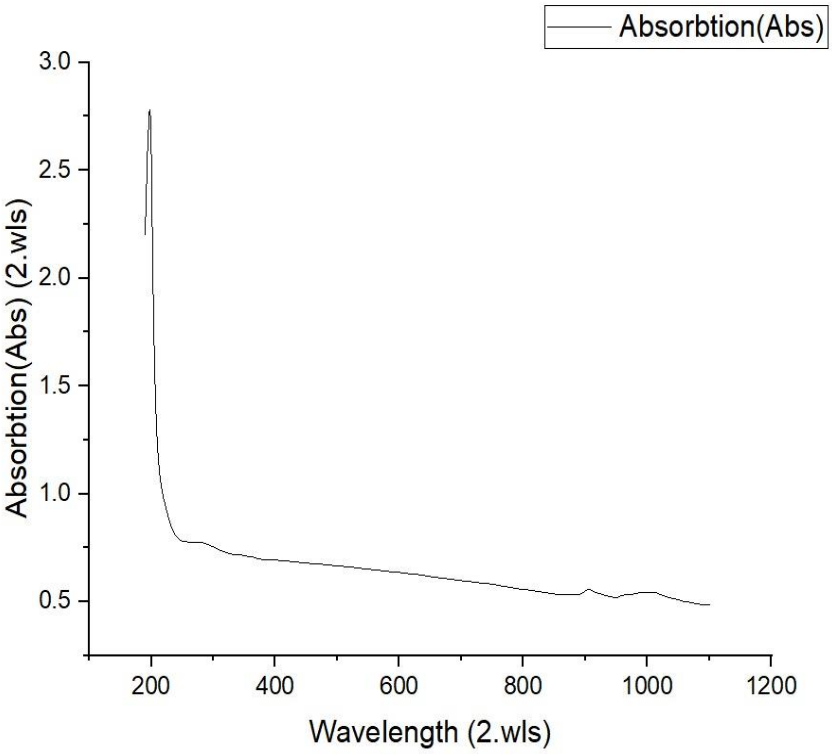


Fig 4.1 UV pattern of prepared materials $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ (x = 0.02, 0.04, 0.06, and 0.08

This spectrum is from a solution containing copper (Cu^{2+}) ions, the high absorbance in the UV region is likely due to charge transfer transitions, and as the concentration of copper increases, the peak at around 200-250 nm will increase in intensity.

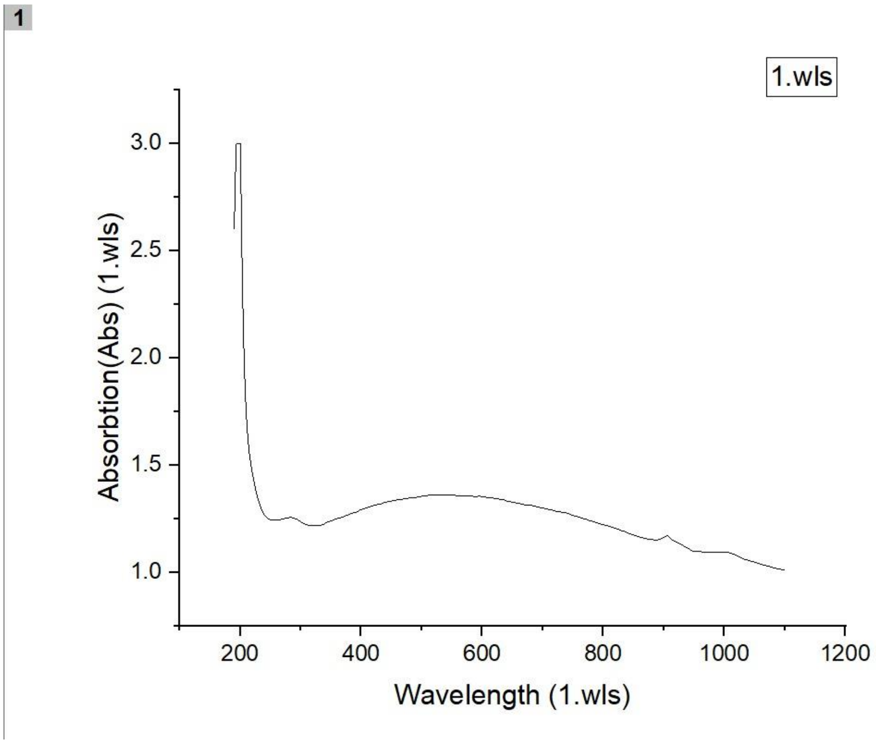


Fig 4.2 UV pattern of prepared materials $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ **(x = 0.02, 0.04, 0.06, and 0.08**

4.2. Microstructural analysis

Structure analysis

The "Issues and Discussion" section initiates with a structural investigation of the Titanate anode, focusing on X-ray diffraction (XRD) analysis of the $La_{0.4}Sr_{0.6}CuxTi_{1-x}O_{3-\delta}$ materials (with varying x values) sintered at 1100°C in an oxygen atmosphere for 6 hours. The XRD results reveal a single-phase, cubic perovskite structure (JCPDS 079-0188) with the space group $pm\bar{3}m$ (221), indicating that this phase forms during the high-temperature sintering process. The analysis shows a subtle shift of diffraction peaks toward lower angles as the Cu content increases, suggesting that Cu incorporation into the $La_{0.4}Sr_{0.6}TiO_3$ (LST) matrix is occurring. The diffraction peaks correspond to various crystallographic planes, and the average crystallite size, determined using the Scherer equation for the dominant (110) peak, is calculated to be 20 nm. Notably, all observed diffraction peaks are attributed to LST, with no discernible peaks for Cu, indicating that Cu doping is within the solubility limit (up to 8 mol %) and that Cu has fully substituted Ti at the B-site. Previous studies by Li et al. and Ali et al. also reported similar doping behavior for other transition metals within their respective solubility limits, with no additional peaks corresponding to these metals. Furthermore, energy-dispersive spectroscopy (EDS) analysis in earlier studies identified La, Sr, Ti, and O as the primary elements in the material, with trace amounts of transition metals (Ni, Fe, Co, and Zn) present. This further supports the successful doping of Cu into the LST structure, as evidenced by the absence of Cu-specific peaks in the XRD patterns.

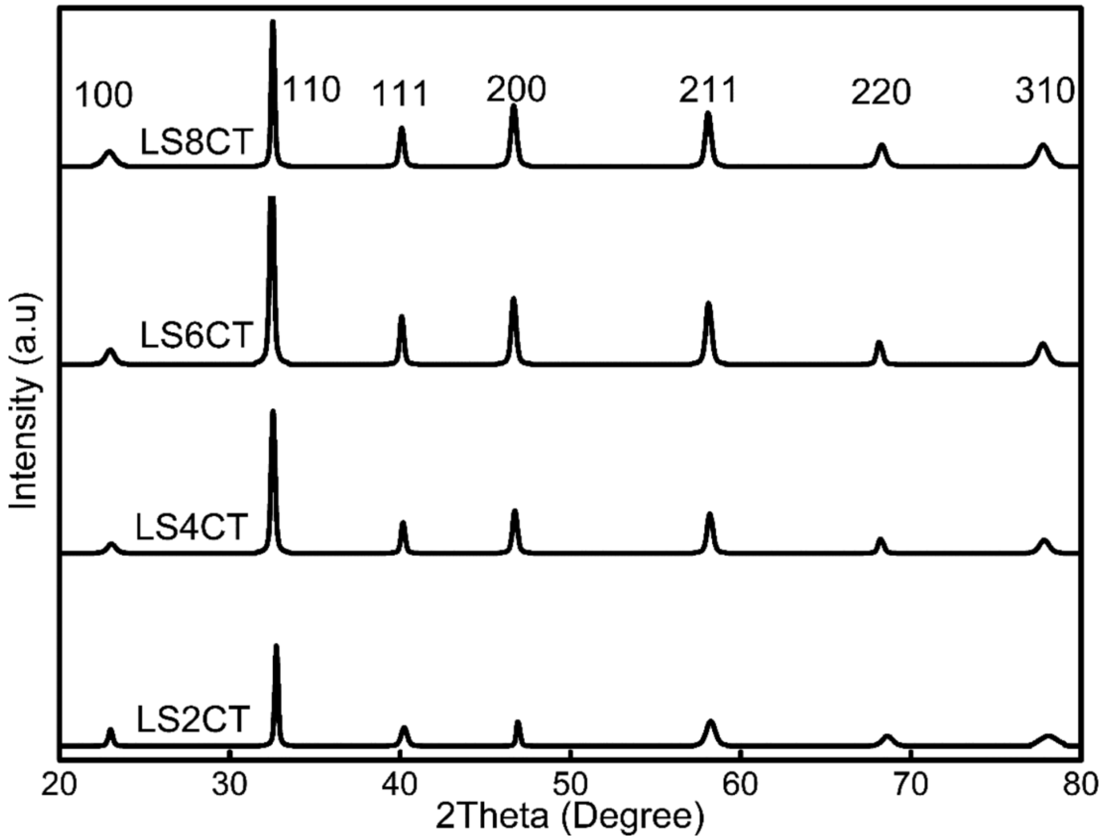


Fig 4.3 XRD pattern of prepared materials $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ (x = 0.02, 0.04, 0.06, and 0.08

4.3. Microstructural analysis

This section presents the microstructural investigation of the as-prepared anode sintered at 1000°C, as shown in Figure 2. The findings indicate that an increase in the concentration of Cu at the B-point leads to the formation of well-distributed patches within the material. The microstructural examination reveals a uniform distribution of these patches throughout the matrix, with voids also visible in the micrographs, suggesting the presence of porosity. SEM images confirm the successful sintering of the materials. Additionally, both the pore size and crystallite size change with Cu concentration. Among the samples studied, the LS8CT sample exhibits a well-formed morphology and enhanced porosity, which promotes higher gas diffusivity and improved electron transfer during cell operation. As a result, LS8CT shows superior conductivity and performance compared to the other samples. Furthermore, the average pore size observed is below 30 nm, indicating a fine distribution of pores, which likely contributes to the improved conductivity and overall performance of the material.

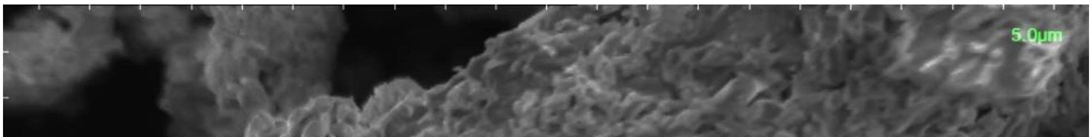
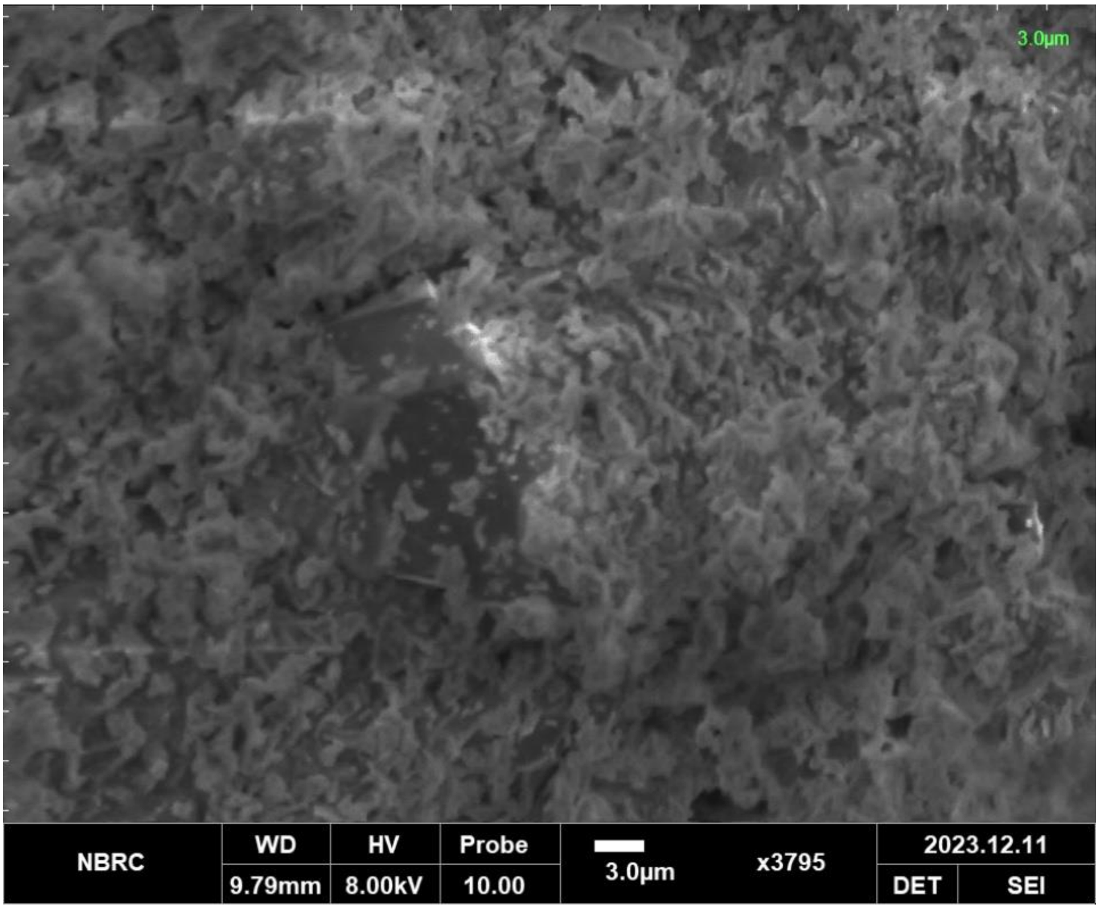
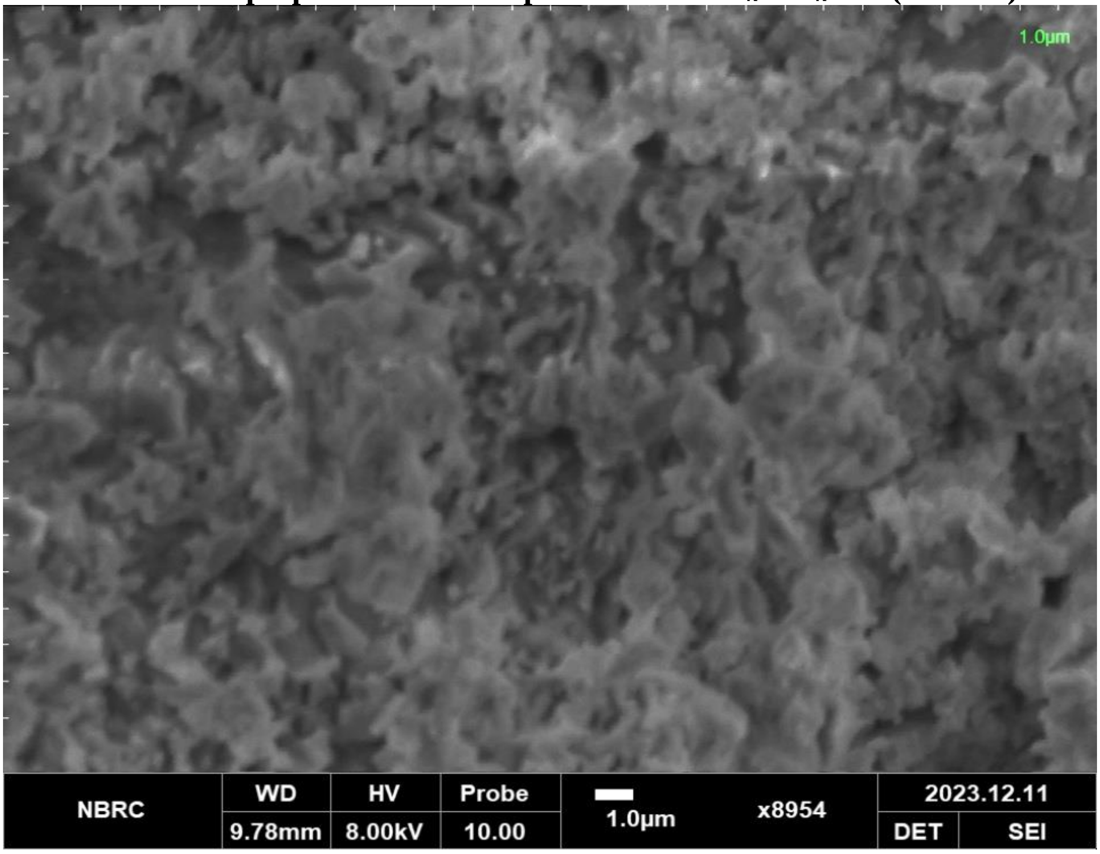


Fig4.4 SEM of the prepared anode samples $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ ($x = 0.04$)



SEM of the prepared anode samples $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ ($x = 0.06$)



SEM of the prepared anode samples $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ ($x = 0.08$)

4.4. Conductivity

To ensure optimal performance of the energy cell device, the anode materials must be matched with other components and maintain thermal stability at elevated temperatures. The electrical conductivity of the anode materials was evaluated in a 5% H_2 atmosphere across a temperature range of 400°C to 600°C, with the results shown in Figure 1. The data show that conductivity increases with temperature, suggesting a metallic behavior. Under reducing circumstance, a notable rise in conductivity was observed, accompanied by a transition from semiconducting to metallic properties. The reduction of $La_{0.4}Sr_{0.6}CuxTi_1{-}xO_{3-}\delta$ materials at high temperatures led to a significant increase in n-type conductivity and a shift from semiconducting to metallic behavior. Among the materials tested, LS8CT exhibited the highest conductivity at 4.21 S/cm, outperforming LS6CT, LS4CT, and LS2CT. The superior conductivity of LS8CT can be attributed to its well-formed structure and enhanced porosity, as depicted in Figure 2(d), when compared to the other samples. The improved conductivity at elevated temperatures is likely a result of sintering at 1000°C, which may have increased the contact between patches and facilitated the formation of voids that contribute to the conduction process.

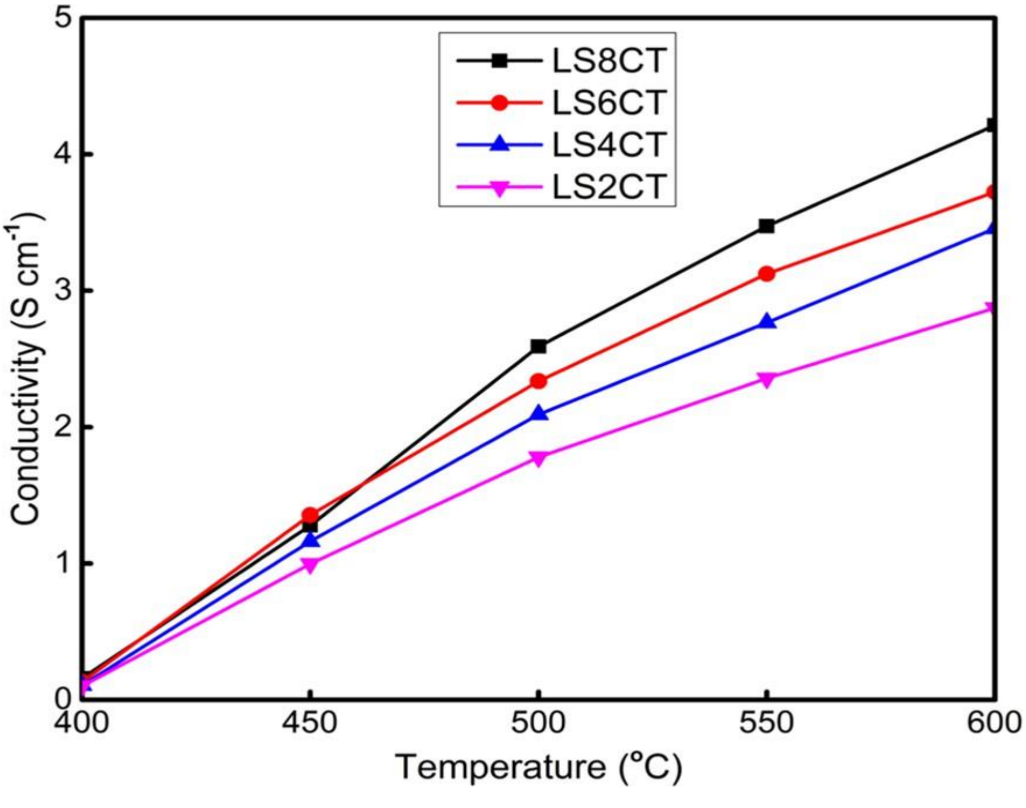


Fig4.5 Conductivity of Titanate anodes $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ (x = 0.02, 0.04, 0.06, and 0.08)

CHAPTER 5

DISCUSION

Conductivity of the titanate-based perovskite, La0.4Sr0.6Cu0.08Ti0.92$O_{3-\delta}$ anode material is 4.21 S cm^{-1} at 600°C. This value proves handy for a relative comparison of conductivity of LS8CT with other titanate based anode materials. Jiang et al examined the electrical conductivity and thermal expansion behavior of Lanthanum-doped $SrTiO_3$ materials for solid oxide cell electrode and interconnect. The researchers established that under the temperature of 600°C the conductivity of LS8CT was 4.21 S cm^{-1} making the material to have high conductivity compared to other titanate-based materials. On the other hand, Li_2TiSiO_5 has been studied as a low-potential high-capacity anodic titanium-based material for lithium batteries. However, the search results do not give the conductivity of Li_2TiSiO_5 directly. Another titanate-based anode material is Lithium titanate (Li_4Ti5O_{12}) which has also been used initially in the lithium-ion batteries. From the search results there are no direct numerical values given for the conductivity of Li_4Ti5O_{12}, the information shows that in most cases XRD and SEM are employed in distinguishing the structure/ morphology of these material's-ray diffraction (XRD) and scanning electron microscopy (SEM) were used to characterize the structural and microstructural properties of the titanate-based perovskite anode material, La0.4Sr0.6CuxTi1-xO_3 (LSCXT). The XRD study of the synthesized LSCXT anodes sintered at 1100°C in oxygen supports all the previous identification and further confirms that Cu has been successfully incorporated in LST lattice since the XRD peaks are shifted slightly towards the smaller angle with an increase in Cu concentration. The average crystallite size calculated using the Scherer equation for the (110) peak was around 20 nm, and the absence of discernible Cu peaks in the XRD patterns suggested that up to 8 mol% Cu doping occurs within the solubility limit, with complete doping in the Ti B-site, consistent with previous studies on doping of other transition metals in LST. SEM investigating further revealed that as the Cu concentration on the B-site increases, the anode materials exhibit well-aggregated particles with a homogeneous distribution throughout the material, with the presence of voids within the micrographs indicating the existence of porosity in the prepared samples, which can facilitate gas diffusion during fuel cell operation. The SEM analysis also confirmed the good sinter ability of the anode materials, suggesting their ability to form a well-densified microstructure during the high-temperature sintering process. ($La0.4Sr0.6Cu0.08Ti0.92O_{3-\delta}$) sample exhibited a well-prepared morphology with enhanced porosity compared to the other samples, with an average particle size detected to be less than 30 nm, indicating a fine particle size distribution. A fine particle size can contribute to several advantages, such as increased surface area, improved sinter ability, and enhanced ionic and electronic conductivity due to the reduced diffusion path lengths. The enhanced porosity and fine particle size distribution of the LS8CT sample are expected to facilitate improved gas diffusion and electron transfer during fuel cell operation, leading to better overall electrochemical performance compared to the other LSCXT compositions. These structural and microstructural characteristics are crucial in determining the functional properties of titanate-based perovskite anode materials for solid oxide fuel cell and lithium-ion battery applications.$La0.4Sr0.6Cu0.08Ti0.92O_{3-\delta}$ (LS8CT) titanate-based perovskite anode material over other LSCXT compositions. The most notable advantage of the LS8CT sample is its enhanced porosity, as revealed by the scanning electron microscopy (SEM) analysis. The SEM micrographs showed that the LS8CT sample exhibited a well-prepared morphology with a higher degree of porosity compared to the other LSCXT compositions. This increased porosity is expected to facilitate improved gas diffusion during fuel cell operation, which is a crucial factor for efficient electrochemical performance. Another key advantage of the LS8CT anode material is its fine particle size distribution. The average particle size of the LS8CT sample was detected to be less than 30 nm, indicating a narrow particle size range. A fine particle size distribution can contribute to several beneficial properties, such as increased surface area, improved sinter ability, and enhanced ionic and electronic conductivity due to the reduced diffusion path lengths. These characteristics are highly desirable for anode materials in solid oxide fuel cell applications, as they can lead to enhanced electrochemical performance. The combination of the LS8CT sample's enhanced porosity and fine particle size distribution is expected to result in superior gas diffusion and electron transport during fuel cell operation, ultimately leading to better overall electrochemical performance compared to the other LSCXT anode compositions. These advantageous microstructural features make the LS8CT material a promising candidate for further development and optimization as a high-performance anode for solid oxide fuel cell applications. Another potential challenge is the sourcing of raw materials, particularly the rare earth elements lanthanum (La) and strontium (Sr) that are present in the LS8CT composition. Securing a reliable and sustainable supply of these materials in the quantities required for large-scale production may be difficult, considering the geopolitical and environmental concerns associated with rare earth element mining and processing. Additionally, maintaining the desired copper (Cu) doping level and distribution during large-scale manufacturing will require careful process control and optimization to ensure the successful incorporation of Cu into the LS8CT lattice.

CONCLUSION

Cu-doped $LaSrTiO_3$ is shown in this study to be a suitable anode material for the solid oxide fuel cells through comparatively high high-temperature stability and structural characteristics. The sol-gel synthesis of LSCT offered good control over the phase constitution and morphology of the perovskite, exhibiting a cubic structure with crystallite size of <30 nm as observed by SEM and XRD studies. The grain size was calculated by using the Scherer's formula and found to be about 20 nm, which is otherwise fine and uniform. The four probe electrical conductivity measurement revealed that the LSCT delivered a maximum conductivity of 4.21 S/cm^{-1} at 600°C. This high conductivity and the mechanical strength of the material at high temperatures, fully fits it for use as SOFC anode. In addition, there are some changes in the electrical and catalytic properties by the introduction of Cu into $LaSrTiO_3$ lattice which still enhances fuel cell performance. Therefore, synthesis and characterization results, in the large extent, confirm the suitability of LSCT as the potential SOFC anode materials combining high strength, proper electrical conductivity, and high catalytic activity. This work presents subsequent framework investigations into enhancement of LSCT and other perovskite materials for future higher SOFC technologies.

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Reports:Titanate Based Perovskite Anode Material for Solid Oxide Fuel Cell (BILAL ISHAQ)

by Haris Mehmood

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Titanate Based Perovskite Anode Material for Solid Oxide Fuel Cell

SUPERIOR UNIVERSITY

Master of Philosophy in Chemistry

By

BILAL ISHAQ

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ABSTRACT

High-temperature and structural characteristics of Cu-doped $LaSrTiO_3$ (LSCT) make it one of the sole anode materials for solid oxide fuel cells (SOFCs). It is pertinent to note that this current work is devoted to the synthesis of LSCT using sol-gel technology, which enables to control over morphology and phase constitution of

compound. Analysis of the material surface topography, by SEM, indicated an average crystallite size of less than 30 nm. X-ray diffraction (XRD) identified the existence of a cubic perovskite structure for the synthesized material and from the Scherrer equation the crystalline size was estimated to be around 20 nm. Electrical conductivity measurements made using the four-probe method visually established that LSCT can generate a maximal power density of 4. 21 S/cm-1 at 600°C. These results exhibit that the material is a promising candidate for anode applications in SOFCs since it displayed both high strength and high electrical conductivity at high temperatures. It seems that the incorporation of Cu into the $LaSrTiO_3$ crystal structure may significantly alter the general conductivity and catalytic properties of this material, making it suitable for the further modification of fuel cells.

Chapter 1

INTRODUCTION

Thus, the inadequacy of natural resources including oil, natural gas and coal has resulted in energy crisis that is affecting the economy and social infrastructure of countries worldwide. The requirement for energy is increasing rapidly due to overpopulation, improvements in lifestyle, industrial and agricultural growth, transportation needs, and other factors. This has put pressure on natural resources, leading to an increase in energy prices, which has affected the economy and social infrastructure of countries worldwide [1]. By burning of fossil fuels, the carbon cycle is being changed especially through injection of CO_2 into the atmosphere. CO_2, as well as CH_4 and NO, is a greenhouse gases maintaining the Earth’s surface temperature between lethal and uninhabitable limits and promoting plant photosynthesis. Nonetheless, rising to 093 ppm since the start of the Industrial Modification Age, carbon dioxide levels now have an impact on climate changes. To reduce the pressure on natural resources, many countries are exploring alternative energy origin like biofuel, biogas, solar energy, tidal energy, wind energy, hydropower, and geothermal power. Renewable and non-renewable energy sources can be used to overcome the burden of electrical energy, and fuel cell technology can be used today. Fuel cells offer numerous benefits above traditional methods of power generation, such as high energy density, proficiency, adjustability, and fuel elasticity However, Alternative energy sources such as small-hydropower, solar cell, wind, geothermal, biomass, ocean, and tidal projects are increasingly favored as sustainable, long-term options for energy production. The development of these alternatives is crucial for the clean and efficient utilization of energy under varying condition [2]. Trust on coal and oil developing, deforestation remains a worry The growing reliance of the region as well with national promises to reduce discharges committed towards cleaner energy sources. Supply: Supply for coal is partly driven by its relative abundance, and the facts that it's cheaper than oil/gas/renewable energy. Unlike renewable energy projects, coal-fired plants are simpler and far easier to finance. Though the region is seeing an influx in renewables, particularly solar and wind — their potential output means countries are still on fossil fuels. Such fuels are needed to provide electricity and 80 percent of which goes into cooking and transport, yet the use is growing as governments seek extended access for entire populations. The IMF indeed projected that 65 million Southeast Asian lack electricity and 251 million use biomass, such as fuel and animal organic, for preparation fuel Global demand for energy is growing swiftly, because of population and economical growth, specially in developing market economies. To backing countries, try to achieve economic growth and development, while certifying that natural possession continue to provide the resources and environmental services on which well-being trusts, a flexible policy framework that can be made-to-order to different country condition and phase of development is proposed. The strategic plan of a new policy emphasizes a more energy efficient, renewable energy source based power generation (solar,wind) and a complete conversion of all modes of transport minimizing coal, oil and natural gas usage. Innovative concepts and new structures will be important in advancing to the next level of energy sustainability. The enhancement of energy alternatives is important to ensure effective energy conservation under such different circumstances. small-hydropower, solar, wind, geothermal, biomass, ocean, tidal program are accepted as appropriate long term energy generation prospects. Nevertheless, the shift to these alternatives is prone to some constraints. As an illustration the United States. The collective population of the country represents slight over 4.0 percent of the world population yet cumulate about 17 percent of the worlds energy consumption. The gross average carbon emissions per head are among some of the high in the world. Currently, the USA, Australia and Canadian resident utilizes approximately 200 times more carbon than outrageously poor yet, rapidly developing nation residents in sub-Saharan Africa such as Chad, Niger and the Central African Republic Combining several population estimates into climate models assuming that this leads to high emissions reduction of the natural resources like oil, natural gas, coal have led to energy crisis causing detriment to the economy and infrastructure of several countries in the world. Pakistan is facing an energy crisis, Pakistan's energy demand is projected to grow exponentially, with an 8-fold rise by 2030 and a 20-fold increase by 2050 [3]. This quick growth, at a rate exceeding 9% annually, highlights the pressing need for sustainable energy solutions in the country. The current energy structure in Pakistan is heavily dependent on thermal origin, such as coal, oil, and natural gas, which are not only costly but also facing severe supply shortages. Additionally, the share of hydroelectricity has importantly decreased in recent years, while renewable energy sources, particularly solar power, possesses the capability to meet these challenges. Solar energy appears as a competitively priced technology worldwide, with the global ability of solar photovoltaic (PV) reaching 402 gigawatts by the end of 2017, accordant to the International Energy Agency. This rapid growth in solar energy adoption underscores its viability as a sustainable solution to Pakistan's energy crisis [4]. By leveraging its abundant solar resources and the cost-effectiveness of solar technology. It will further grow just about 580 GW and lead the renewable electricity volume evolution. The oil and gas industry is also facing challenges due to geopolitical and macroeconomic uncertainty, supply disruptions, and price volatility. However, the industry is focused on securing supply in the short term while conversion to cleaner energy in the long term. The industry is positive about the future, with a healthy balance sheet and continued capital discipline. For almost 2 decades the European commission has conducted research programs on solar energy aimed at reducing carbon emission and pollution, enhancing energy security and expanding energy sources of European nations. The global weighted-average level cost of electricity for recently commissioned utility-scale solar photovoltaic (PV) projects experienced a substantial 85.0% decrease between 2010 and 2020. In comparison, the cost reductions for concentrated solar power (CSP) stood at 68.0%, onshore wind at 56.0%, and offshore wind at 48.0%. This significant cost decline underscores the development competitiveness of renewable energy sources, positioning them as the primary choice for capacity expansions in the power sector across various nations. Solar and wind technologies have solidified their leading impression over time, with the recent surge in fossil fuel prices further enhancing the economic practicality of renewable power solutions. This trend highlights the increasingly favourable economic outlook for renewable energy in the global energy backdrop. The improvement of solar energy in Pakistan is crucial for the clean and economic utilization of energy under varying conditions. The combined installed volume of solar reached 843.0 GW globally by the end of 2021, with 133 GW of capacity commissioned in 2021 alone, with 57.0% of the commencement in Asia. The development of solar energy in Pakistan can help the country to cut down its habituation on fossil fuels and move towards a more bearable energy upcoming. Pakistan is facing an energy crisis due to the increasing demand for energy, which is growing by more than 9% annually. The leading reason for the energy crisis in Pakistan the energy structure is primarily dependent on thermal resources, including coal, oil, and natural gas, which are costly and under immense pressure of shortage. As mentioned, the enhancement of solar energy in Pakistan is important for the proper and efficient production of energy in different circumstances. It is not an easy exercise to begin the shift to solar energy and this will call for the following changes; the use of energy has to increase much faster, producing it from renewable resources, and electrifying transport to scale back the usage of coal, oil, and natural gas. Long term the oil and gas industry is also moving to clean energy which underscores the need to come up with other sources of energy such as hybrid power and fuel cell technologies to build the foundation for a cleaner future.

1.1. Renewable energy sources

Energy is a very important part of sustainable improvement, and sustainable energy systems are necessary for achieving sustainable development. While renewable energy sources have made significant progress in the last few decades, with double-digit percentages of renewable energy penetration in electricity supply in various countries, many other countries and sectors like transportation are still in the initial stages of renewable energy adoption [5].The overall renewable and nonrenewable energy sources are show in fig 1.1.

1.1.1.Wind Energy

Wind farms have been positively mounted on-shore since the 1990s, masking decide with the quality wind resources. some of the set up wind generators have surpassed 1/2 of their anticipated lifespan and agreement durations, however the mastering curve of wind electricity generation has advanced exponentially seeing that then This focuses on the authentic valorization of an standing wind farm and the efficacy of the exploitation of the site's wind aid[6].

1.1.2. Solar Energy

Solar energy is a low-cost and plentiful supply of strength that is healthy for numerous programs. The preservation cost for solar electricity systems is also low however, the primary drawback of solar strength is that it is problem to climate irregularity, which means that that it requires an energy storage gadget to make certain a non-stop supply of electricity[7].

1.1.3. Biomass Energy

By 2050, it's miles predictable that 90% of the sectors can also belong to in growing international locations consequently, biomass strength is likely to remain a huge power feed stock. Biomass sources can be used for direct heating in industrial or domestic situation, within the manufacturing of steam for energy technology, or to supply gaseous and liquid fuels [8]

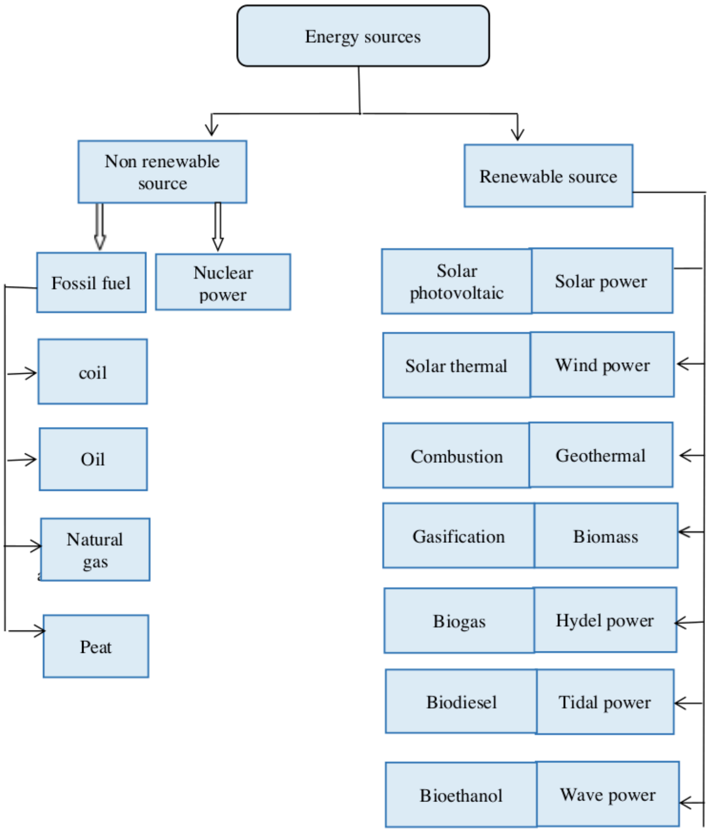
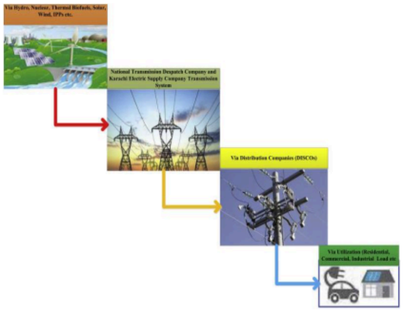


Fig1.1: Renewable and non-renewable energy source

1.2. Power sector organization mission in Pakistan

The production, distribution, and consumption of electricity in Pakistan is a complex process that involves several stages and various companies. By 2022, the nation's total installed electricity generation capacity reached 41,557 MW, with over 80% of the population having access to power. The country's electricity sector is primarily overseen by two main public organizations: Development Authority (WAPDA) and Karachi Electric (formerly KESC)[9], which oversee generation, transmission, distribution, and retail supply. In addition, approximately 42 power producers (IPPs) play an important role in supplying electricity to national grid. The energy breakdown in 2022 was 63% thermal (fossil fuels), 26% hydropower, 3% from renewable sources (wind, solar, and biomass), and 8% from nuclear energy. Pakistan aims to source 60% of its energy from renewables, including hydropower, by 2030. The country holds significant potential for electricity generation from Thar coal, hydro, wind, and solar energy. Despite increasing its power capacity, Pakistan continues to face electricity shortages and struggles to balance supply and demand. Moreover, the high reliance on fossil fuel capacity has led to rising electricity costs and concerns about achieving its climate targets fig1.2.



1.2: Fig Power sector organizations in Pakistan.

1.3. Fuel cell technology

Fuel cells produce electricity by transforming the chemical energy found in fuels through an electrochemical process, without producing harmful emissions. They offer several advantages over conventional power generation methods, such as higher energy density, efficiency, flexibility, and the capacity to utilize multiple types of fuels. Solid Oxide Fuel Cells (SOFCs) have demonstrated high effectiveness for electricity generation across many commercial applications. The efficiency and design of SOFCs are critical for their success. This research focuses on developing a cost-efficient, reliable, and durable anode material that could be used to create high-performing, eco-friendly SOFCs.The outlook for the oil and gas industry in 2023 is uncertain due to global political and economic challenges, supply chain disruptions, and price fluctuations[10]. However, the industry is focused on securing energy supplies in the short term while working toward cleaner energy solutions in the future. Despite the uncertainty, the industry maintains a positive outlook, with strong financial stability and continued capital discipline. Current trends emphasize the growing need for alternative energy sources and fuel cell technology, which are seen as critical in creating a sustainable energy future. Government policies are essential in decreasing reliance on fossil fuels. Significant investment and global cooperation are needed to encourage the advancements of different energy options and fossil cell technologies. These policies can help lower energy consumption, improve energy security, and fund the transition to sustainable energy without increasing costs. Governments must work together to create strategies that support a cleaner, more sustainable energy future. Fuel cells, with their numerous benefits, stand out as a key technology in this transition., including:

i. High energy density

ii. High efficiency

iii. Adjustability

iv. Fuel flexibility

v. Low emissions

One key benefit is their ability to function at higher efficiencies compared to combustion engines. Fuel cells can directly transforms the chemical energy within the fuel into electrical energy with efficiency rate that can exceed 60%. This direct conversion process eliminates the need for intermediate steps, such as heat production and mechanical energy transformation, which have been essential in combustion-based systems, leading to higher overall efficiency.

Components of fuel cell

Three main components of FCs

FCs have three main constituents' anode, cathode, and solid ceramic electrolyte.

Anode

Oxidation of the fuel (H_2) occurs at anode surface with the aid of a catalyst. Losing electrons from the fuel move through the circuit and generate current in the circuit.

$$2H_2 \longrightarrow 4H^+ + 4e^-$$

Cathode

The cathode distributes the oxygen on its surface it comes from air and conducts electrons from the circuit. After gaining electrons from the circuit the oxygen changed into oxygen ions which passed across the electrolyte and joined with hydrogen ions to form H_2O and heat as a by-product shown in fig 1.3.

$$O_2 + 4e^- + 4H^+ \longrightarrow 4H_2O$$

The overall fuel cell reaction is,

$$2H_2 + O_2 \longrightarrow 2H_2O$$

Electrolyte

The electrolyte helps determine the operative temperatures of the cell and allows the charged ions to pass from itself to maintain the electrical charge balance. The electrolyte can also act as the oxygen ions and proton conductor.

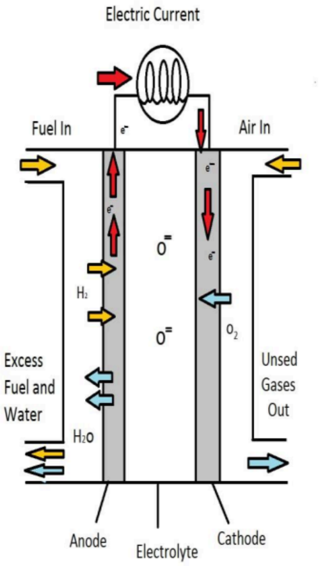


Fig 1.3: Hydrogen based fuel cell

1.4. The importance of alternative energy sources

Despite activity to promote renewable energies as an alternative to fossil fuels, fossil fuels continue to give significantly to universal electricity production. In 2017, fossil fuels contributed 72% worldwide electricity production, while renewable sources impart only 26%. The primary fossil fuels are coal, natural gas, and oil Renewable energy origin include geothermal, wind, solar, and hydroelectric power.

1.5. Types of fuel cell

1.5.1. Proton-exchange membrane fuel cell

Proton exchange membrane fuel cells (PEMFCs) have seen significant progress, driven by the growing demand for clean and sustainable energy. However, there are still several challenges at both the device and infrastructure levels that must be addressed before these fuel cells can be economically feasible for commercial scale. One of the key obstacles is increasing the power density of PEMFCs, with various global targets in place. For instance, Japan's New Energy and Industrial Technology Development Organization (NEDO) has set power density goals of 6 kilowatts per liter by 2030 and 9 kilowatts per liter by 2040[11].To achieve these objectives, several technological innovations are being explored, particularly in enhancing the membrane electrode assembly (MEA) and its components. Improvements in water and thermal management, as well as new materials, are predicted to play a crucial role in next-generation PEMFCs, enabling higher power density. Addressing these challenges requires a thorough understanding of all aspects of PEMFC technology.

Recent research has focused on innovative design approaches made possible by advances in micro- and nanofabrication techniques, such as inkjet printing, template-based patterning, and thin-film deposition. A promising development is the use of fluted electrode designs, which improve material utilization and transport processes, leading to higher power density, greater durability, and better fuel efficiency. Additionally, machine learning has shown potential in further optimizing these designs, allowing for the development of smaller, more cost-efficient PEMFC stacks with enhanced performance and fuel efficiency.

1.5.2. Solid alkaline fuel cell

Solid alkaline fuel cells (SAFCs) with anion exchange membranes (AEMs) have gained considerable attention in recent years, emerging as a key focus within renewable energy technologies. This is largely due to their high electrode activity, the potential to use non-precious metal catalysts, and relatively low fuel purity requirements. The AEM plays a pivotal role in these fuel cells, facilitating ion conduction, preventing fuel crossover, and supporting the catalysts. The efficiency and longevity of fuel cells are directly influenced by the performance of the AEM. Alkaline fuel cell technology, particularly anion exchange membrane fuel cells (AEMFCs), has been thoroughly researched. These fuel cells rely on an AEM to separate the anode and cathode chambers, allowing for the transport of alkaline anions, typically hydroxide ions (OH−), between the electrodes. The development of polymer membranes capable of transporting hydroxide ions has been a notable advancement. Additionally, the crosslinking of anion-conducting materials with stable, sterically-protected organic cations has proven to be an effective method for creating durable AEMs. This strategy enhances both the durability and performance of AEMs, improving the overall efficiency and lifespan of solid alkaline fuel cells. Research has also charted the development of anion-conducting membranes for these applications, shedding light on the evolution of this technology. Moreover, diagrams of alkaline anion exchange membrane fuel cells (AAEMFCs) have been provided to illustrate their operational principles[12].

1.5.3. Direct methanol fuel cell

Fuel cell is an application that converts chemical energy to electricity through chemical reactions that are distinct from burning. These are applied in various uses including the supply of power to residents and firms, and transportation of cars, buses, and trains. The majority of fuel cells operate on hydrogen which can be supplied directly to the fuel cell system or produced in the system by reforming hydrogen-rich fuel such as methanol, ethanol and hydrocarbon fuels. DMFCs use pure methanol, often dissolved in water and supplied to the anode of the fuel cell directly. A major advantage of direct methanol fuel cells is that some of the fuel storage issues unique to certain fuel cell systems, such as lack of energy density of hydrogen, are not typical of this type of fuel cell, though the density is lower than that of such fuels as gasoline or diesel. It is also easier to transport and supply using the current substructure because, like gasoline, methanol is a liquid substance. Thus, DMFC are employed for portable fuel cell applications Such as cell phones and laptop computers. There are some advantages of the fuel cells compared to the traditional combustion requiring technologies, or conversely, the main benefits include higher efficiency, zero or low emissions, and flexibility of fuels. Some can efficiently operate with power conversion capabilities in excess of 60% and deliver power to sizes ranging from a utility power plant to a laptop computer. Fuel cells are then compounded through research and development provided by NASA and private industry to be a substitute for the internal combustion engine, thereby altering the utility industry by making energy purer, cheaper, and portable. Washington is supporting the study of the hydrogen fuel cells to foster the generation of clean energy to support its cheapness in the future world energy market [13].

1.5.4. Phosphoric acid fuel cell

Phosphoric acid energy cells (PAFCs) represent the" foremost generation" of ultramodern energy cells and are one of the most constituted cell types commercially available. They use liquid phosphoric acid as an electrolyte, contained in a Teflon-clicked SiC matrix, and passable carbon electrodes containingts operation. PAFCs are generally used for inactive power generation, with some also being employed to power huge vehicles similar as megacity motorcars. They're known for their acceptance of contaminations in fossil energies changed into hydrogen, making them suitable for similar operations. still, they're lower profitable at generating electricity alone compared to other energy cell types, with an effectiveness range of 37 – 42%[14]. When used for theco-generation of electricity and heat, Phosphoric acid energy cell can attain over 85 effectiveness, making them suitable for certain operations. Despite their benefits, PAFCs have limitations. They're less important, larger, and heavier compared to other energy cell types, and they bear advanced ladings of expensive platinum catalyst, making them fairly precious. Yet, they've set up operations in fixed power creators with affair in the 100 kW to 401 kW range and in larger vehicles similar as motorcars. PAFC technology has been developed and bettered significantly over the times, making it a good seeker for early stationary operations. Major a Pt catalyst. The electrochemical responses that take place in the cells are pivotal for imanufacturers of PAFC technology include Doosan Fuel Cell America Inc. and Fuji Electric. also, PAFCs have been used for air-independent thrust in submarines.

1.5.5. Molten carbonate fuel cell

Molten carbonate fuel cells (MCFCs) are integrated advanced high temperature fuel cells suitable for power station, natural gas or coal fired plants, industries utilities and military usage. These cells exploit an electrolyte that is molten carbonate salts imbedded in a tough solid matrix of lithium aluminum oxide. These are functioning at around 650 centigrade (1150 Fahrenheit) temperate and MCFCs have the advantage of having non-precious metal both at the anode and the cathode. Indeed, MCFCs have some benefits that are clearly visible compared to the phosphoric acid fuel cells, such as better efficiency than PAFCs. Incorporation into a turbine system enables these cells to attain near 65 per cent efficiency, which is considerably higher than the 37 per cent to 42 per cent range apparent in PAFC systems. Furthermore, should the waste heat generated in the cell be utilized, then the general fuel efficiency is over 85 %. The MCFC technology is different from other types of fuel cells that include alkaline, phosphoric Acid and polymer electrolyte membrane fuel cells as they do not require an external reformer to develop fuel such as natural gas or biogas into hydrogen. Because of the high operating temperatures, it is possible to reform methane and other light hydrocarbons to hydrogen as a part of the overall cell internal reforming, which is cost effective. However, there are few drawbacks of using MCFC technology such as durability or long life. Operating temperatures are high, and electrolyte is usually corrosive thus degrading the cell components and shortening the overall life of the system. These are problems are being marked by researchers who are working day and night to come up with corrosion-resistant materials and make some small changes in the design of these cells in order to make these cells last longer by not compromising with efficiency.[15]

Table: 1.2. Comparison of the fuel cells

Fuel cell Type	**Common electrolyte**	**Operating Temp. C^0**	**Efficiency %**	**Applications**
Polymer Electrolyte Membrane (PEM)	Ion Exchange membrane	50-100	40-50	Backup power Movable power Distributed Generation Transportation
Alkaline Fuel Cell (AFC)	Aqueous Solution of KOH	150-200	40-70	In Military In Space
Phosphoric acid fuel Cell (PAFC)	H_3PO_4	150-200	40-80	Distributed Generations
Molten Carbonate (MCFC)	Na_2CO_3 or $MgCO_3$	600-700	40-50	Electric use Distributed Generations
Solid oxide (SOFC)	YSZ	700-1000	60	Auxiliary power Electric use Distributed generation

1.5.6. Solid oxide fuel cell

1.5.6.1. History

Baur and Preis in 1937 gives the concept of SOFC by using ceramic material at 1000^0C different researchers in 1962 at Westinghouse worked on this cell by using zirconia oxide and calcium oxide. Now a days, in all over the world researchers worked on SOFC by using different materials as an electrodes and electrolyte to gain the maximum efficiency [16].

1.5.6.2. Characteristics of SOFCs

Strong oxide fuel cells (SOFCs) are a kind of cell which utilize a thick ceramic fabric as the electrolyte. These fuel cells work at greatly tall temperatures, around 1000°C, and can change over fuel into power with an effectiveness of around 60%. When arranged for co-generation, where squander warm is captured and reused, in general fuel proficiency can surpass 85%[17]. The tall temperatures dispense with the require for costly precious-metal catalysts, which makes a difference lower costs, and permit for inner fuel transforming. This implies SOFCs can handle a assortment of fills, counting common gas, biogas, and coal-derived gasses, without requiring an outside reformer. SOFCs too have the advantage of being safe to sulfur and unaffected by carbon monoxide, which makes them more flexible than numerous other fuel cell sorts. In any case, the tall working temperatures posture a few challenges. These incorporate slower startup times, the require for broad warm cover to hold warm and guarantee security, and the necessity for materials that can withstand the unforgiving conditions. The fundamental specialized jump is creating cost-effective materials that can persevere these tall temperatures. Research is underway to make lower-temperature SOFCs, working at or underneath 700°C, in trusts of tending to these solidness issues and cutting costs. Whereas this approach appears guarantee, lower-temperature SOFCs have however to coordinate the execution of their higher-temperature partners, and the look for appropriate materials proceeds.

1.5.6.3. Importance of SOFCs fuel cell

Different sorts of fuel cells have their claim benefits and downsides. Among them, (SOFCs) have picked up noteworthy consideration because of higher efficiency, cost-effectiveness, and the desire to use a different kinds of fills other than hydrogen, like hydrocarbons and coal gas Strong Oxide Fuel Cells SOFCs are a promising innovation for creating power for a wide extend of applications in the commercial segment.SOFCs offer several advantages over traditional procedures of power generation, including:

Tall productivity: SOFCs can accomplish efficiencies of up to 60%, which is essentially higher than routine strategies of control generation.

Fuel flexibility: SOFCs can utilize a run of fills, counting common gas, biogas, and hydrogen.

Low emanations: SOFCs deliver exceptionally moo outflows, making them an ecologically neighborly alternative for creating electricity.

Durability: SOFCs have a long life expectancy and can work for tens of thousands of hours without critical degradation.

Scalability: SOFCs can be used for numerous applications ranging from residential level systems, to distributed generation systems to large central power stations. Storing energy chemically as fuel and oxidant in a fuel cell involves conversion of the chemical energy of a fuel, hydrogen in most instances, and an oxidizing agent, oxygen in most instances, into electrical energy via an electrochemical process. Fuel cells comprise of three adjoining portions: The anode, the electrolyte, and the cathode. At the interfacing of the three different parts of a hybrid chemical system, there are two chemical reactions. The net outcome of the two responses is that fuel is exhausted, water or carbon dioxide is moulded Another outcome is that an electrical current is delivered, which can be utilized to control electrical gadgets, regularly specified to as the stack [18].

Here is a step-by-step process of how fuel cells work:

1. Fuel, like hydrogen, is fed to the anode.

2. Oxygen or air is fed to the cathode.

3. Hydrogen molecules are split into electrons and protons at the anode.

4. The protons pass through the permeable electrolyte membrane, while the electrons are enforced through a circuit, generating an electric current and excess heat.

5. At cathode, oxygen combines with the electrons or protons to form water or carbon dioxide.

Like the name suggests, there is a solid oxide electrolyte in operation in the SOFCs. SOFCs are very favorable in medium and large power condition sectors. The current progress, as well as the future prospective of SOFCs, have been examined in the present review article by comparing the literature available over the last five years.

Must of the existing review described a literature based on positions of certain SOFC constituents, namely anode, cathode and electrolyte. Current advances and future standpoints of SOFCs have been discussed in the present review article by reviewing the literature over the last five years. Most of the existing review discussed the literature in positions of specific SOFC components, such as anode, cathode, and electrolytes. On the other hand, this review has reviewed the literatures in the province of two sorts of SOFC stack designs; linear and tubelike which are widely employed to integrate effective SOFC devices. Several studies have focused on the execution of a stack system for a novel design of SOFCs. The stack design is a crucial aspect of SOFCs, and it affects the performance, cost, and manufacturability of the device. The literature review outlined that one of the major used material sets of SOFCs is the flat-tubular design. This design combines the benefit of both planar and tubular SOFCs, resulting in a high-power output at low operating temperatures [19].

1.5.6.4. Design and operation of SOFC

SOFC are very differ than other types of the FCs. First of all their all parts (electrodes and electrolyte) are composed of solid material. Secondly these cells drive at high temperature but other FCs drive at low temperature. Solid state components of the SOFCs show that there is not fundamental restriction on the shape of cell. SOFCs categories into two main types, one is tabular cells or rolled tubes and flat -plates that's are applicable today in electronic industry. SOFCs consist of solid ceramic electrolyte(zirconia)which is present in between the anode and cathode Fuel is fed at anode while oxidant at cathode side. Fuel is oxidized at anode by losing the electron and oxidant reduce at cathode side by gaining electrons. the O_2 ion move toward the anode side by the porous electrolyte surface that maintained the overall electrical charge balance. there is an electrical connection in between the anode and cathode that's help in flow of the electron's anode to cathode pure water and heat are the byproduct in SOFCs these byproducts are used for co-generation purpose [20].

1.5.6.5. SOFCs reaction

Anode side reaction

$$H_2+O^{-2} \longrightarrow H_2O+2e^- \qquad (1)$$

$$CO+O^{-2} \longrightarrow CO_2+2e^- \qquad (2)$$

$$CH_4+4O^{-2} \longrightarrow 2H_2O+CO_2+8e^- \qquad (3)$$

Cathode side reaction

$$O_2+4e^- \longrightarrow 2O^{-2} \qquad (4)$$

There are three main components of FCs

Solid oxide fuel cell have three main constituents

Anode, Cathode and solid Electrolyte

Anode

Oxidation of fuel (H_2) takes place at anode surface in the presence of a catalyst.

Cathode

The cathode distributes the oxygen on surface comes from the air and conducts electrons from the circuit. After gaining electrons from the circuit the oxygen changed into oxygen ions which passed across the electrolyte and joined with hydrogen ions to form H_2O and heat as a byproduct.

Electrolyte

The electrolyte helps determine the operative temperatures of the cell and allows the charged ions to pass from itself to maintain the electrical charge balance. The electrolyte can also act as the oxygen ions and proton conductor. Flow diagram of SOFC is shown in fig 1.4.

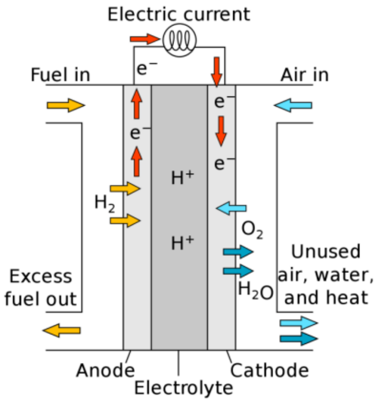


Fig 1.4 Hydrogen base SOFCs

1.5.6.6. SOFC components requirements

- Proper stability
- Proper conductivity
- Chemical compatibility with other components
- Electrolyte is dense that prevent the reactants mixing

- Porous electrode
- Higher toughness and strength properties
- Low cost components
- Operate at high temperature and not crack

Table 1.3 Material for SOFC

Electrolytes	**Anodes**	**Cathodes**	**Interconnects**	**Seals**	**Rr**

Zirconia Materials YSZ SSZ CaSZ **Ceria material** GDC SDC YDC CDC **La material** LSGM LSGMC LSGMF MSGMCF **Other material** YSTh YSHa BCY Bismuth oxide Based Ba and Sr Pyrochlor	**Nickel Material** Ni-O/YSZ Ni-o/SSZ Ni-O/SDC Ni-O/GDC **Copper Materials** CuO2/CeO2/YSZ CuO2/YZT CuO2/YSZ CuO2/CeO2/SDC **Lanthanum Materials** LaSrCrO3 LST LaSrCrMO3 LAC **Other materials** TiO2/YSZ CeO2/YS Cobalt based Platinum based Ru/YSZ	Lanthanum Materials LSM and LSF LSC and LSCF LSMC and LSMCr LCM and LSCu LNF and LSFN LSCN and LBC LNC and LSAF LSFNCu and LSCNCu LNO **Gadolinium Materials** GSC GSM **Praseodymium Materials** PSM PCM PBC **Strontium materials** NSC and SSC BSCCu **Yttria materials** YCCF and YSCF YBCu	**Metals based Materials** Chromium Alloys Iron allays Ferritic stainless Steel Austenitic Stainless steel **Coatings** LCM SM LSC LSFeCo LSCr LaCo3 **Ceramics** Lanthanum Chromites	Glass or glass Cermic Materials Mica-based composits	[21]

Chapter 2

LITERATURE REVIEW

Solid Oxide Energy Cells are a bright technology for polluted and effective energy product. One way to ameliorate their performance is by incorporating Sn answer in [3] Ni/ YSZ as an anode catalyst, along with functional subcaste deposited among the anode and electrolyte. Kan et al.(2010) demonstrated that Sn doping can achieve advanced temperature and power viscosity in SOFCs. By using methane gas(CH_4) as energy, the Sn- unravel Ni/ YSZ cell demonstrated a advanced power viscosity of 0.41Wcm- 2 at 650 ^{o}C[22]. The Sn- unravel Ni/ YSZ cells also operated for a vastly longer period of 136 hours, compared to the Ni/ YSZ cell which operated for only 27 hours. These findings suggest that Sn doping is a serious factor in perfecting the performance of the SOFC, as it leads to the loftiest cell effectiveness. farther exploration has also shown that Sn- unravel Ni/ YSZ catalysts have bettered dry reforming of biogas at SOFC operating conditions. still, [42] the electrochemical performance of the SOFC is veritably delicate to the volume of Sn unravel into the Ni/ YSZ anode, and repeated cell tests are necessary to optimize the Sn lading variation. In addition, strategies for carbon and sulfur tolerant SOFC accoutrements have been proposed, incorporating assignments from miscellaneous catalysis. These studies punctuate the significance of Sn answer in cultivating the performance and stability of SOFCs, and suggest that farther exploration is demanded to optimize the Sn lading and other factors to achieve indeed advanced effectiveness and continuity. To expand on the content of SOFCs, it's important to understand the background and environment of this technology. SOFCs are [56] a type of energy cell that convert chemical energy directly into electrical energy, with high effectiveness and low- position radiations. They operate at high temperatures(generally800-1000^{o}C), which allow for [69] the use of a variety of energies, including hydrogen, natural gas, and biogas. SOFCs have the eventuality to revise the energy assiduity by furnishing clean and dependable power for an expansive range of operations, from domestic and marketable structures to transportation and assiduity. Still, there are numerous tasks to overcome before SOFCs can come a conventional technology. One major challenge is the high cost of accoutrements and manufacturing, which limits the scalability and marketable viability of SOFCs. Another challenge is the continuity and trustability of SOFCs, which can be affected by factors similar as thermal cycling, energy contaminations, and electrode degradation. To address these challenges, experimenters are exploring new accoutrements, designs, and manufacturing processes for SOFCs, as well as developing advanced individual and monitoring tools to ameliorate their performance and lifetime. Sn doping is critical aspect in perfecting the performance of SOFCs, as demonstrated by Kan et al.(2010) and other studies. still, there are still numerous dares to overcome before SOFCs can come a mainstream technology, and farther exploration is demanded to optimize their effectiveness, continuity, and scalability[23].

Morel et al.(2007) conducted a study on symmetrical LaO.8 SrO.2 MnO_3(LSM) cells in a single chambered solid oxide energy cell(SC- SOFC) terrain to probe their catalytic exertion for different methane- to- oxygen rates. The experimenters examined the oxidation responses at electrode sintered at 1100 °C and 1200 °C and used electrochemical resistance spectroscopy(EIS) to track the effect of burning. The study set up that the catalytic exertion of the LSM electrode increased with temperature and the change in oxygen(O_2) species at temperatures above 700 °C could exceed 30 percent, leading to oxygen reduction and the emergence of low- frequence fractions in EIS spectra. The study also set up that the rise in sintering temperature dropped the catalytic exertion, and the LSM electrode performed more at 600 °C than at 700 °C. The study by Morel et al.(2007) provides precious perceptivity into the catalytic exertion of LSM electrodes in SC- SOFCs. The results suggest that the catalytic exertion of LSM electrodes is largely reliant on temperature and sintering conditions. The rise in temperature leads to an increase in catalytic exertion, but also to oxygen reduction and the emergence of low- frequence fractions in EIS spectra. This suggests that the optimal operating temperature for LSM electrodes in SC- SOFCs is around 600 °C, where the catalytic exertion is high but the threat of oxygen reduction is minimized. The study also highlights the significance of sintering conditions in determining the catalytic exertion of LSM electrodes. The rise in sintering temperature decreases the catalytic exertion, which suggests that careful control of sintering conditions is essential to optimize the performance of LSM electrodes in SC- SOFCs. The use of EIS to track the effect of burning provides a precious tool for covering the performance of LSM electrodes in real- time, and could be used to optimize the operating conditions of SC- SOFCs. Overall, the study by Morel et al.(2007) provides important perceptivity into the catalytic exertion of LSM electrodes in SC- SOFCs, and highlights the need for farther exploration to optimize the performance of these electrodes. The use of advanced individual tools similar as EIS could help to develop the effectiveness and continuity of SC- SOFCs, and could pave the way for the expansive relinquishment of this promising technology[24].

Resini et al.(2008) examined the performance of Ni- YSZ as a protagonist substantial for solid oxide energy cells(SOFCs) fueled by bioethanol. The study aimed to determine the optimal catalyst material for the anode face of SOFCs fueled by ethyl alcohol. The investigators set up that the addition of cobalt(Co) to the Ni- YSZ catalyst material redounded in the topmost performance. The recently synthesized Ni- Co/ YSZ catalyst material showed the loftiest performance among all the catalyst accoutrements tested.The study by Resini et al.(2008) provides precious perceptivity into the use of bioethanol as a energy for SOFCs and the optimal catalyst accoutrements for the anode face. The results recommend that the addition of cobalt to the Ni- YSZ catalyst material can significantly ameliorate the performance of SOFCs fueled by bioethanol. This finding has important counteraccusations for the development of more effective and supportable energy cell technologies. farther exploration is asked to optimize the performance of SOFCs fueled by bioethanol and to explore the use of other renewable energies. The use of advanced individual tools similar as electrochemical impedance spectroscopy(EIS) could help to ameliorate the productivity and continuity of SOFCs, and could pave the way for the wide relinquishment of this promising technology. In addition, the hunt results give farther perceptivity into the use of catalysts for energy cell technologies, including the use of glycerol as abio-syngas precursor via reforming route. The results suggest that the performance of catalysts can be bettered by enhancing size distribution and active phase dissipation. These findings punctuate the significance of catalyst accoutrements in energy cell technologies and the need for farther exploration to optimize their performance and continuity. Overall, the study by Resini et al.(2008) and the related hunt results give important perceptivity into the use of catalyst accoutrements for energy cell technologies and the need for farther exploration to optimize their performance and continuity. These findings have essential implications for the improvement of more efficient and sustainable energy technologies, and could help to pave the way for a cleaner and more sustainable future [25].

Ye et al.(2008) audited the use of a catalyst subcaste(Cu- CeO_2) on the anode face for solid oxide energy cell(SOFC) fueled by ethanol. The study anticipated to determine the optimal catalyst material for the anode face of SOFCs fueled by ethanol.

The experimenters set up that the circumstance of the catalyst material on the anode face redounded in a advanced power viscosity of 567mWcm- 2 at 800 oC operating on ethanol energy. The study also showed that the anode material could discharge for as long as 80 hours without carbon deposit, indicating long- term performance. The study by Ye et al.(2008) provides precious perceptivity into the use of catalyst accoutrements for SOFCs fueled by ethanol. The results suggest that the presence of a catalyst subcaste on the anode face can significantly ameliorate the performance of SOFCs fueled by ethanol. This finding has important counteraccusations for the development of more effective and sustainable energy cell technologies. farther exploration is demanded to optimize the performance of SOFCs fueled by ethanol and to explore the use of other renewable energies. The hunt results give fresh perceptivity into the use of catalyst accoutrements for energy cell technologies, including the use of NiCr2O3- CeO2NRs anode electrocatalyst for ethanol electrooxidation response in alkaline media. The results suggest that the resistance to catalytical poisoning of NiCr2O3- CeO2NRs is better among the synthesized catalysts. The evidence of a catalyst subcaste with unanticipated catalytic exertion for carbonous energies over the nickel- grounded anode has also been established as an factual way to ameliorate the performance of SOFCs. Determining the optimum subcaste fattiness, for the anode and cathode, is of topmost significance for minimizing the costs of the(DEFC). These findings punctuate the significance of catalyst accoutrements in energy cell technologies and the need for farther exploration to optimize their performance and continuity. In addition, the hunt results give perceptivity into strategies for C and S tolerant SOFC accoutrements , incorporating assignments from miscellaneous catalysis. These studies suggest that the actuality of a largely oxygen conductive phase in the anode authorities a certain degree of electrochemical oxidation of sulfur to grease sulfur junking. These findings have important consequences for the development of further durable and reliable SOFCs that can operate on a wide range of energies. Overall, the study by Ye et al.(2008) and the related hunt results give important perceptivity into the use of catalyst accoutrements for energy cell technologies and the need for farther exploration to optimize their performance and continuity. These findings have important counteraccusations for the growth of more effective energy technologies, and could help to pave the way for a cleanser and redundant sustainable[26]. Ullah et al.(2018) delved the use of rare earth essence, including samarium(Sm), cerium, and gadolinium(Gd), in the electrolyte and catalyst accoutrements of(SOFCs). The study anticipated to determine the optimal catalyst material for the anode face of SOFCs fueled by ethanol. The experimenters set up that the use oftri-doped(M = Sm, Ca, Gd) ceria MO.2CeO.8O2- δ as an electrolyte redounded in a lower functional temperature compared to conventional electrolytes. The electrical conductivity of the set samples was measured using a Probo- Stat-NorECs setup, which showed a conductivity of 1.2 × 10^{-2} Scm- 1 at 700^{o}C. Raman and UV-visible spectroscopy were used to characterize the set samples, to check the absorbance and molecular climate. The crystal clear structure was measured byx-ray diffraction, which showed that the dopants were effectively unravel in CeO_2. The set samples handed a power viscosity of 314 mW cm^{-2} by using ethanol energy at 550 ^{o}C. The study by Ullah et al.(2018) provides appreciated perceptivity into the use of rare earth essence in SOFC and the optimal catalyst accoutrements for anode face. The results recommend that the use oftri-doped ceria as an electrolyte can significantly ameliorate the performance of SOFCs fueled by ethanol. This finding has important counteraccusations for the development of more effective and sustainable energy cell technologies. farther exploration is demanded to ameliorate the performance of SOFCs fueled by ethanol and to explore the use of other renewable energies. The hunt results give fresh perceptivity into use of rare earth essence in energy cell technologies, including their use in the product of high- performance attractions, blends, spectacles, and electronics. The results suggest that rare earth essence similar as cerium, lanthanum, and neodymium are important catalysts for petroleum refining and as diesel complements. The use of rare earth essence in the product of energy cells and nickel- essence hydride batteries has also been demonstrated as an effective way to ameliorate the performance of SOFCs. These findings punctuate the significance of rare earth essence in energy cell technologies and the need for farther exploration to optimize their performance and continuity. In addition, the hunt results deliver perceptivity into the cornucopia and uses of rare earth essence in ultramodern technologies and life. The results suggest that rare earth essence are used in a wide variety of operations, including the defenses of smartphones, computers, and other bias, automotive catalytic transformers, attractions, and sword timber. These findings have important counteraccusations for the sustainability and environmental impact of ultramodern technologies, and could help to inform programs and practices aimed at reducing the use ofnon-renewable coffers. Overall, the study by Ullah et al.(2018) and the related hunt results give important perceptivity into the use of rare earth essence in energy cell technologies and the need for farther exploration to optimize their performance and continuity. These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to cover the way for a cleaner and further sustainable future [27].Mushtaq et al.(2018) studied the use of Ti- unravel SrFeO3 as a cathode material for solid oxide cells(SOFCs). The study aimed to determine the optimal cathode material for SOFCs operating at low temperature. The experimenters set up that the use of Ti- unravel SrFeO3 as a cathode material redounded in maximum performance at low temperatures. The cathode material was prepared using the sol- gel system, and its structure, morphology, and thermo gravimetric characteristics were delved using different ways. The boxy perovskite structure of the cathode was verified byx-ray diffraction. The electrical conductivity the set samples was measured using the four-inquiry system, which showed a conductivity of 1.2 × 10^{-2} Scm^{-1} at 700 °C. The equipped cathode material gave a power viscosity of 551 mW cm^{-2} at 600 °C when using ethanol energy.The study by Mushtaq et al.(2018) provides precious perceptivity into the use of Ti- unravel $SrFeO_3$ cathode material for SOFCs operating at low temperatures. The results suggest that the use of Ti- unravel $SrFeO_3$ as a cathode material can deliberately expand the performance of SOFCs operating at low temperatures. This finding has important counteraccusations for the development of more effective and sustainable energy cell technologies. farther exploration is demanded to ameliorate the performance of SOFCs operating at low temperatures and to explore the use of other renewable energies. The hunt results give fresh perceptivity into the use of different accoutrements for energy cell technologies, including the use of rare earth essence, similar as cerium, lanthanum, and neodymium, as catalysts for petroleum refining and as diesel complements. The use of different deposit styles for oxides, similar as stabilized zirconia, has also been established as an effective way to ameliorate the performance of SOFCs. These findings punctuate the significance of accoutrements in energy cell technologies and the need for farther exploration to optimize their performance and continuity. In addition, the hunt results give perceptivity into the medication and characterization of solid electrolytes for energy cell operations. The results suggest that the sol- gel system is a useful fashion for the grounding of spectacles and thin film samples, and that the use of different deposit styles can significantly ameliorate the performance of energy cells. These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to pave the way for a cleaner and further sustainable future. the study by Mushtaq et al.(2018) and the related hunt results give important perceptivity into the use of different accoutrements for energy cell technologies and the need for farther exploration to optimize their performance and durability.These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to cover the way for a cleaner and further sustainable future[28].

Ali et al.(2018) delved the use of LNK- SDC electrolyte and LNCZFO electrode accoutrements for direct carbon energy cells(DCFCs). The study aimed to determine the optimal accoutrements for DCFCs that could use different carbonaceous energies, similar as carbon, carbon filaments, graphite, lignite, bituminous coal, watercolor, and other redundant accoutrements , to convert their chemical energy into electrical energy. The electrolyte material was synthesized using theco-precipitation system, and the electrode material was prepared using the solid- phase response system. The boxy crystalline structure of the material was verified usingx-ray diffraction. The electrical conductivity of the set samples was measured using the four- inquiry system, which showed an ionic conductivity of 0.0998 Scm^{-1}for the electrolyte(LNK- SDC) and an electronic conductivity of 10.1 Scm^{-1}for the electrode(LNCZFO) at 700^{o}C. The set accoutrements handed a power viscosity of 58 mWcm^{-2} when usingsub-bituminous energy.

The study by Ali et al.(2018) provides precious perceptivity into the use of LNK- SDC electrolyte and LNCZFO electrode accoutrements for DCFCs that can use different carbonaceous energies. The results propose that the use of these accoutrements can significantly ameliorate the prosecution of DCFCs and enable the conversion of a wide range of carbonaceous energies into electrical energy. This finding has important counteraccusations for the development of further emotional and sustainable energy cell technologies. farther exploration is demanded to enhance the performance of DCFCs and to explore the use of other renewable energies. The hunt results give fresh perceptivity into the use of different material for energy cell technologies, including the use of molten carbonate electrolytes and ceria- grounded compound electrolytes. The results suggest that the use of different deposit styles for oxides, similar as stabilized zirconia, has also been established as an operative way to ameliorate the performance of SOFCs. These findings punctuate the significance of accoutrements in energy cell technologies and the need for farther exploration to optimize their performance and durability. In addition, the hunt results give perceptivity into the operating characteristics of DCFCs completed of different construction accoutrements , similar as carbon sword, pristine sword, and nickel. The results propose that the use of different construction accoutrements can significantly affect the vacuity and continuity of DCFCs, and that the selection of applicable accoutrements is critical for the successful operation of DCFCs. These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to pave the way for a cleaner and further sustainable future.Overall, the study by Ali et al.(2018) and the related hunt results give important perceptivity into the use of different accoutrements for DCFCs and the need for farther exploration to optimize their performance and continuity. These findings have important counteraccusations for the development of more effective and sustainable energy technologies, and could help to cover the way for a cleaner and further sustainable future.Doped- $SrTiO_3$ is a type of anode material that has gained attention due to its excellent stability under both oxidizing and reducing conditions, reasonable thermal expansion, and high forbearance to sulfur and carbon deposit. also, strontium Titanates are chemically well- suited with the most considerably used solid electrolytes up to 1400°C, similar as Zr0.82Y0.16O 1.92(YSZ), La0.8Sr0.1Ga0.8Mg0.2O3- δ(LSGM), and Ce 0.9 Gd 0.1O 1.95(CGO). still, the performance of strontium Titanates is rather modest compared to the state- of- the- art anode accoutrements due to their deprived ionic conductivity and electrocatalytic exertion[29].

The performance optimization of SrTiO3-based anode materials has recently garnered attention. For instance, one article published on ResearchGate deals with the creation of an anode material in the form of lanthanum-substituted strontium titanate perovskite doped with manganese and gallium for the application in Solid Oxide Fuel Cells. It was found that the perovskite structure is thermally stable in both oxidizing and reducing environments and maximum power density is obtained for anode composed of both manganese and gallium doped material. Another research also described the performance of NiO-doped SrTiO3 (Ni-STN) and its application as an anode material for SOFCs claiming redox stability. The role of the Ni-STN material was found to enhance catalytic activity and stability during redox cycles. Although SrTiO3-based anode materials possess some interesting properties, their performance level still needs further enhancement to be suitable for SOFC anode applications. There is a positive trend in research focused on enhancing the performance of these materials, however, further research work is required to achieve the maximum efficiency of the materials in application.Recently, nanocomposite materials have gained considerable attention for increasing the electrochemical activities of conventional air electrodes with the combination of Ce0.9Gd0.1O1.94 (CGO) for example La0.8Sr0.2MnO3-δ (LSM) and La0.5Sr0.4Co0.2Fe0.8O3-δ (LSCF). In high-temperature sintering processes, the introduction of CGO aids in decreasing the formation of pores, leading to the development of nanocomposite electrodes with a higher number of active regions for the ORR. For instance, LaCrO3-CeO2 nanocomposites were treated as symmetric electrodes, which exhibited exceptional performances with 0.29 and 0.09 Ω cm2 for polarisation resistance at temperatures of 750°C when placed in the atmosphere and hydrogen respectively.The improvement of the hydrogen performance has been related to the remarkable characteristics of nanostructured electrodes and the nano-CeO2 which is also a good catalyst for many electrocatalytic processes. To improve the electrochemical properties of air electrodes of SOFCs, it was possible to propose new nanocomposite electrodes which can be obtained by Pr-doped SrTiO3±δ and CGO, these electrodes are said to have high redox stability and improved performance for both oxygen reduction reaction (ORR) and hydrogen oxidation reaction (HOR) in symmetric SOFCs. The nanocomposite electrodes in this case would have smaller grains owing to inhibition of pore development providing more active spots for ORR and HOR for enhanced effective activity. This particular method could allow for the fabrication of more efficient and stable air electrodes for the SOFCs. All in all, the combination of nanocomposite materials shows a bright outlook for the enhancement of air electrodes in SOFCs. The combination of Pr doped SrTiO3±δ and CGO will give rise to new electrodes that will have high redox stability and thus better performance hence moving towards the production of advanced and more stable SOFCs with the prospects of being useful in clean energy technologies. A more recent literature review addresses the application of the different biofuels (liquid, e.g. pyrolytic oils, alchohol, biodiesel, solid – biochar, gaseous syngas and biogas) in IT-SOFCs, alsonatching biofuels regions to materials for electrodes and electrolytes that target SOFC use with oxygenated biofuels at the intermediate temperatures.The review, for its part, seeks to advance the theory by explaining some of the more competing electrochemical processes that ensue in the anode when biofuels are directly fed. Attempts are made to qualitatively explain the electrochemical processes that take place in IT-SOFCs using oxygenated biofuels, by looking typically at the chemistry at the anode. This model is further extended to IT-SOFCs operating on methanol and it analyzes the causes of poor performance of these fuel cells having biofuels. The review encompasses progress in materials and techniques for SOFC operation in reduced temperatures that are achieved through advancement of anode, electrolyte and cathode materials to operate SOFCs below 6000C Further it highlights the basics of SOFC, selection of electrolytes materials and fabrication of materials inside SOFCs. The review also looks at the questions related to design and operational characteristics of energy cells, including electrodes in SOFCs which determine the performance[30].

Bilayer Y_2O_3- stabilized ZrO_2(YSZ)/ Sm_2O_3- unravel CeO_2(SDC) electrolyte flicks were appreciatively made- up on pervious NiO – YSZ emulsion face using electrophoretic deposit(EPD) followed byco-firings with the substrates. In the EPD process, appreciatively charged YSZ and SDC maquillages were deposited straight on the face, subcaste by subcaste from ethanol- grounded dormancies. Delamination between YSZ and SDC flicks was avoided by reducing the SDC flicks' consistence to roughly 1 µm. A single cell was made on the bilayered electrolyte flicks composed of roughly 4.0 µm-thick YSZ and roughly 1.0 µm-thick SDC flicks. La 0.6 Sr 0.4 Co 0.2 Fe 0.8 O3 − x(LSCF) was used as the cathode in the cell, and maximum affair power consistence lesser than 0.6 W cm^{-2} were attained at 700 °C for the bilayered YSZ/ SDC electrolyte cells therefore constructed(31).A promising material for use in the anode cube of solid oxide energy cells(SOFCs) operating at 650 °C isA-site lacking strontium Titanate- La 0.2 Sr 0.7 TiO_3. This material can be reduced at high temperatures(1000°C) and shows sufficient conductivity, enhanced energy oxidation, and bettered current collection parcels through impregnation with active accoutrements. Button cells were fabricated, conforming of a passable frame of this electronically conductive material saturated with CGO and Cu as the energy electrode, and YSZ as the electrolyte, to test the energy cell performance. Morales M, Espiell F, Segarra M.Anode- supported single- chambered solid oxide energy cell(SOFCs) were studied with NiGDC/ GDC/ LSC- GDC, with and without Cu – ZnO – Al_2O_3 catalyst layers on the anode face, worked on ethanol and air fusions. The optimal operating circonstance were determined at a cell temperature of 450 °C, an ethanol- air molar rate of 0.44, and a total gas inflow rate of 400 ml min −1. also, the cells should be concerned with perpendicularly to the gas inflow direction with the cathode exposed to the fresh gas. Recent exploration has concentrated on anode- supported SOFCs, similar as those with Ni- YSZ/ YSZ/ GDC/ LSC, which are suitable for intermediate temperature(below 800°C) SOFC exploration and development. Anode- supported single- chamber SOFCs have also been studied in air fusions, using a YSZ solid electrolyte with a Nikel anode and LSM cathode. likewise, the catalytic exertion of Platinum and Nikel- grounded anodes for the deficient oxidation of methane has been investigated.Anode- supported SOFCs grounded on Gd- unravel ceria(GDC) electrolyte and NiO- GDC anode have been made- up by the gel- casting system for direct- methane operation under catalytic partial oxidation(CPOX) conditions. The study demonstrated the good stability of Ni- GDC anode and support under CH_4/ air as energy, indicating its eventuality for championing the internal catalytic reforming of methane towards CPOX .Kan H, Lee H. Tin-doped Ni/YSZ was employed as an anode activator for the fabrication of single SOFC cells. To achieve high power density at intermediate temperatures, a functional layer was added between the majority anode and the electrolyte. The performance and stability of single cells with the same microstructure were compared for Nikel/YSZ and Sn-doped Nikel/YSZ anodes. Key findings include, Similar power densities were obtained for Ni/YSZ and Tin-doped Ni/YSZ single cells (0.39 W cm^{-2} vs. 0.41 W cm^{-2}), indicating comparable performance Sn-doped Ni/YSZ demonstrated enhanced long-term stability (27 h vs. 137 h), which can be attributed to a lower rate of deposition of amorphous carbon.The stability of the Tin-doped Ni/YSZ cell was further improved when carbon deposited on the surface during operation was removed.These results highlight the potential of Tin-doped Ni/YSZ anode catalysts in intermediate temperature SOFCs, offering enhanced carbon deposition rsistance and long-term stability [32].

Ye XF, Wang SR, Wang ZR, Xiong L, Sun XF, Wen TL.Anode- supported SOFCs rested Gd- unravel ceria(GDC) electrolyte and NiO- GDC anode support have been made- up by the gel- casting system for direct- methane operation under catalytic partial oxidation(CPOX) conditions. also, progress has been reported on the use of conductive anode catalysts, analogous as LiLaNi- Al2O3 and bull, in SOFCs for methane internal perfecting and partial oxidation[33].Energy is a vital factor for the profitable progress of a country. Pakistan, like multitudinous other underdeveloped countries, relies simply on conventional archconservative powers to meet its energy conditions. Due to its enormous population and recent artificial development, there is a vast demand for energy. still, archconservative energy prices have enlarged recently, and the country has no other means to produce energy, performing in energy faults. The electricity demand and force gap has increased extremely, and all sectors of life have been severely affected. Policy makers worldwide are looking for alternate ways of energy to break energy failure problems. Different sources of alternate and renewable energy are being explored in Pakistan as well. Solar and wind energy sources have been compared predicated on price, average life span, emigration of dangerous feasts, ingesting of energy, operation, and conservation charges. Solar energy has surfaced as the swish source of renewable energy to attack all the energy challenges as it's cheaper, does n't bear operation or conservation costs, and has a better average life span than wind energy[34].Renewable energy sources, analogous as solar and wind, are naturally refilled and do n't run out. They can be used for electricity generation, space and water heating and cooling, and passage. In Pakistan, where 60 of electricity is generated through precious imported archconservative powers and coal, there is a dire need for affordable electricity and environmental protection. The country has set ambitious targets to increase the share of renewable energy in the public power grid from 5 to 20 in 2025 and to 30 in 2030. Solar energy, in particular, has surfaced as an attractive alternate energy result for the common millions in Pakistan, with the eventuality to meet the country's current electricity demand[35].

Research in the field of SOFCs has focused on enhancing coking resistance to improve the performance and resilience of the cells, particularly when using carbon-containing fuels. Various studies have demonstrated the effectiveness of different catalysts and materials in mitigating the impact of carbon deposition on the anodes of SOFCs. These advancements are crucial for the practical application of SOFCs in energy conversion from a extensive range of fuel sources, including methane, biogas, and ethanol[36]. The development of well-organized and stable photocatalysts for environmental remediation applications has been a subject of intense research. The use of quantum dots, such as copper sulfide, has shown great potential in enhancing the photocatalytic activity of TiO_2 nanotubes. The resulting composites have been evaluated for the photodegradation of organic dyes, such as malachite green and phenol, with promising results [37].

The study's findings emphasize the eventuality of conductive polymer binders in enhancing the performance of lithium- ion battery anodes, particularly those grounded on silicon. By reining the electrical conductivity of the anode and adding the active material content, the exploration contributes to the ongoing sweats to optimize the capacity parcels of Li- ion batteries. These advancements are pivotal for the practical operation of lithium- ion batteries in colorful energy storehouse and conversion systems, including electric motorcars and grid- scale energy storehouse[38]. The anode- supported SOFC with a NiO- YSZ anode, YSZ electrolyte, and GDC- LSM‖LSM complex cathodes displayed excellent chemical stability, firm cell structure, and promising electrochemical performance. The continuity evaluation demonstrated the cell's capability to repel long- term operation and thermal cycles, making it a feasible seeker for practical SOFC applications.The new synthetic route enabled the successful conflation of Ln2/ 3 − xTiO3 −3 x/ 2(Ln = La, Pr, and Nd) composites with enhanced densification. The optimized precursor medication and the sol – gel system proved to be effective for utmost lanthanide compositions, except for cerium. The electrical characterization of La- and Pr- grounded LTOs revealed their eventuality for colorful operations taking effective charge transport parcels[39]. The new synthetic route enabled the successful conflation of Ln2/ 3 − xTiO3 −3 x/ 2(Ln = La, Pr, and Nd) composites with enhanced densification. The optimized precursor medication and the sol – gel system proved to be effective for utmost lanthanide compositions, except for cerium. The electrical characterization of La- and Pr- grounded LTOs revealed their eventuality for colorful operations taking effective charge transport parcels [40]. The citric acid–nitrate process was successfully employed to synthesize LSTC materials with a single-phase perovskite structure and outstanding chemical compatibility with YSZ. The chromium doping up to 20 mol% did not disrupt the perovskite structure. The LSTC powders exhibited a nanoparticle size distribution, and the sintered pellets showed a highly densified microstructure. These results suggest that LSTC is a capable candidate material for SOFC applications, particularly as a cathode or interconnect material [41]. This study demonstrates the promising electrochemical performance of LSFNT-based anodes for SOFC applications. The anode compositions exhibited high peak power densities and fuel utilization, making them attractive alternatives to conventional Ni:YSZ composite electrodes. The redox stability and corrosion resistance of LSFNT-based anodes offer a significant advantage over traditional anode materials, pavement the way for the development of more efficient and durable SOFC[42]. Efficient and stable operation of MS-SOFCs relies on the development of LSM/8YSZ cathodes that can be formed without high-temperature sintering processes.

By focusing on the interfacial properties between the cathode, electrolyte, and composite phases, researchers can optimize the electrochemical behavior of the cell, leading to improved performance and long-term stability. This approach is crucial for advancing the development of MS-SOFCs with enhanced efficiency and durability[38]. Metal-supported SOFs (MSCs) have emerged as an attractive alternative to conventional anode-supported cells (ASCs) for various applications, particularly in the field of mobile auxiliary power units (APUs) , . MSCs offer several advantages, such as lower production costs and improved ruggedness, making them suitable for harsh operating conditions. However, the use of metallic substrates necessitates specific adaptations to the SOFC processing technologies to avoid oxidation during high-temperature sintering under oxidizing atmospheres[39]. The thin metal-supported SOFC developed in this study shows promise for mobile or portable applications due to its enhanced mechanical flexibility and durability. The successful fabrication and characterization of this cell demonstrate the potential of this design for improving the overall performance and consistency of SOFCs[43].

The strong correspondence of both electrode materials and simplicity of construction of the cell are very important for the further development of (SOFC) technology.gy. In this work, bi-functional hybrid material, LaNi0.82Fe0.17O3 (LNF)/NiO was prepared by a one-pot citrate method and used as quasi-symmetrical electrode catalysts of SOFCs. The LNF and Ni (reduced NiO) components behaved as cathodic and anodic electrodes' catalysts, respectively.

Further, LSGM based asymmetrical tri-layered substrates were prepared with a screen-printing assisted co-firing technique [44].

PSFNM perovskites doped with molybdenum were synthesized by an improved Pechini technique and employed as both anode and cathode in intermediate temperature SSOFCs. In the theoretical aspect, the study aim to explore the impact of Mo-doping on the following properties of Pr0.6Sr0.4Fe0.8Ni0.2O3-δ (PSFN) electrodes: the structural change, electrical conductivity, coefficient of thermal expansion and electrochemical performance [45].

The integration of the SFM predecessor solution into a three-ply LSGM support structure made it possible to produce SFM/LSGM bipolar fuel cells and also practical fuel cells on an ultra-rapid and efficient basis. The choice of cell structure in terms of geometries has favoured high TSHR and the good match of the TEC between the SFM and the LSGM to steadfast the structural stability of the fuel cells. The small difference in polarization resistance of the SFM/LSGM composite electrodes suggest the great electrochemical activity of these bipolar fuel cell structures [46].

Chapter 3

MATERIAL AND METHOD

3.1. Synthesis

2

3.1 Sol gel method

The sol-gel technique is a very extended well-known since the late 1800s[47]. The sol-gel is a wet chemical method use to fabricate thin film, powder, or fibers. Molecular precursors are dissolved in H_2O or ROH and changed into a gel by heating or stirring the raw materials. Material thus developed will be dried using a suitable method, various methods have been represented in literature examples oven dry, air dry.The sol-gel method is a widely used technique for the preparation of many materials, including perovskite anode materials. The method involves dissolving molecular ancestors in water or alcohol and converting them into a gel by heating or stirring the raw materials. The resulting gel is then dried to form a powder or film. The sol-gel method is a inexpensive and low-temperature technique that permission for the fine control of the product's chemical composition. The sol-gel method can be used to prepare perovskite catalysts, membranes, and powders, among other materials. For example, the Sol-Gel Pechini method is a adaptable procedure for preparing perovskite membranes. The method involves chelate poly esterification and is commonly used for depositing dielectric coatings. However, the method is very sensitive to moisture and can be difficult to scale up. It can also include several steps and is a time-consuming process. The sol-gel formation of perovskites by an EDTA/citrate complexing method contains nanoscale solid-state reactions. The method permits for the precise control of the product's chemical composition and the formation of phase-pure products. Double perovskite Sr_2FeMoO_6 can be prepared by the sol-gel technique and solid-state reaction method. The resulting dusts from gel and solid-state reaction methods were characterized and compared. The sol-gel method was found to produce a more homogeneous product. A layered double perovskite oxide with A-site ordered layered structure can be prepared via a sol-gel method and studied as the DC-SOFC anode material. The method involves dissolving molecular precursors in water or ROH and converting them into a gel by heating or stirring the raw materials. The resulting gel is then dried to form a powder or film. The sol-gel method is a useful and extensively used technique for the synthesis of various materials, including perovskite and oxide [48].

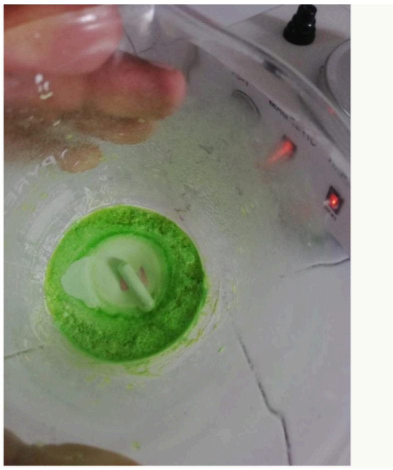


Fig.3.1. Gel obtained at 80C^0 continuous heating and stirring 4 hours

3.2. Preparation (LaSrCuTiO$_{3-0}$) by wet chemical technique

LaCuTiO powers as anode for SOFC were prepared by sol get way. The stoichiometric amount 25 of,

Lanthanum hex nitrate La $(NO_3)_3$ 6H_2O (sigma Aldrich 99.99%)

Strontium nitrate Sr $(NO_3)_2$

Copper (II) nitrate trihydrate $Cu(NO_3)_2.3H_2O$(Glenthan)

Titanium (IV) oxide TiO_2 (riedel-detlaen)

Were used in this synthesis.an appropriate molar ratio of strontium nitrate Lanthanum hex nitrate $La(NO_3)_3.6H_2O$ and Copper(II) nitrate trihydrate $Cu(NO_3)_2.3H_2O$ dissolved into 150ml distilled water and heat at 120^o C in a hot magnetic stirrer. Titanium (IV) oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^o C through the hot magnetic stirrer. After heating and stirring TiO_2 solution at 120^o C for half hour, add it into $La(NO_3)_3$. $6H_2O$, and $Cu(NO_3)_2$ H_2O solution. Citric acid was added 20% of the total moles of LCuT into solution. After that, this overall solution was heated continuously at temperature 120^o C for 8h to obtain gel. The obtaining gel was dry at 120^o C for four hours in an oven and crushed in motar pestle to achieve powder. Then followed by calcination at temperature 1000^o C for five hours. Finally, the fine powder were grounded and ready for characterization.In this way total four samples were prepared with different concentrations, these samples were,

Sample F_1

4.3301g Lanthanum hex nitrate $La(NO_3)_3.6H_2O$ and 0.966g copper nitrate trihydrate $Cu(NO_3)_2.\ 3H_2O$ dissolved into 150ml distilled water than heat and stir at 120^o C, Titanium oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add 1.437g of TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^o C.After heating and stirring TiO_2 solution, add it into the previous solution. Citric acid was added 20% (2g) of total moles of $LCuTiO_{3.0}$ into solution. After that, this overall solution was heated continuously at temperature 120^o C for 8h to attain gel. The gel was dried at 120^o C for four hours in an oven and crushed in mortar pestle to attain powder. Then followed by calcination at temperature 1000^o C for five hours. Finally, the fine powder was grounded and this sample F_1 was ready for characterization.

Fig 3.2. Solution of Lanthanum hex nitrate, Strontium nitrate, Copper nitrate and Titanium oxide heat and stir about $120C^0$

Sample F_2

4.3301g Lanthanum hex nitrate $La(NO_3)_3.\ 6H_2O$ and 0.193g copper nitrate trihydrate $Cu(NO_3)_2.\ 3H_2O$ dissolved into 150ml distilled water than heat and stir at 120^o C, Titanium oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add 1.437g of TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^o C. After heating and stirring TiO_2 solution, add it into the previous solution. Citric acid was added 20% (2g) of total moles of $LCuTO_{3.0}$ into solution. After that, this overall solution was heated continuously at temperature 120^o C for 8h to attain gel. The gel was dried at 120^o C for four hours in an oven and crushed in mortar pestle to attain powder. Then followed by calcination at temperature 1000^o C for five hours. Finally, the fine powder was grounded and this sample F_2 was ready for characterization.

Sample F_3

4.3301g Lanthanum hex nitrate $La(NO_3)_{3.}$ $6H_2O$ and 0.289g copper nitrate trihydrate $Cu(NO_3)_{2.}$ $3H_2O$ dissolved into 150ml distilled water than heat and stir at 120^o C, Titanium oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add 1.437g of TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^o C.After heating and stirring TiO_2 solution, add it into the previous solution. Citric acid was added 20% (2g) of total moles of $LCuTO_{3.0}$ into solution. After that, this overall solution was heated continuously at temperature 120^o C for 8h to attain gel. The gel was dried at 120^o C for four hours in an oven and crushed in mortar pestle to attain powder. Then followed by calcination at temperature 1000^o C for five hours. Finally, the fine powder was grounded and this sample F_3 was ready for characterization.

Sample F_4

4.3301g Lanthanum hex nitrate $L(NO_3)_{3.}$ $6H_2O$ and 0.386g copper nitrate trihydrate $Cu(NO_3)_{2.}$ $3H_2O$ dissolved into 150ml distilled water than heat and stir at 120^o C, Titanium oxide TiO_2 is insoluble in H_2O but soluble in strong acid. So take 10ml concentrated hydrochloric acid and add into 10ml distilled water, then add 1.437g of TiO_2 into this mixture of acid and water, heat and stirring for half hour at temperature 120^o C.After heating and stirring TiO_2 solution, add it into the previous solution. Citric acid was added 20% (2g) of total moles of $LCuTO_{3.0}$ into solution. After that, this overall solution was heated continuously at temperature 120^o C for 8h to attain gel. The gel was dried at 120^o C for four hours in an oven and crushed in mortar pestle to attain powder. Then followed by calcination at temperature 1000^o C for five hours. Finally, the fine powder was grounded and this sample F_4 was ready for characterization.These four samples were used in SOFC as anode material for to improve its conductivity.

Fig 3.3: Powder form sample obtained after dry and sintering at 900^{0}C

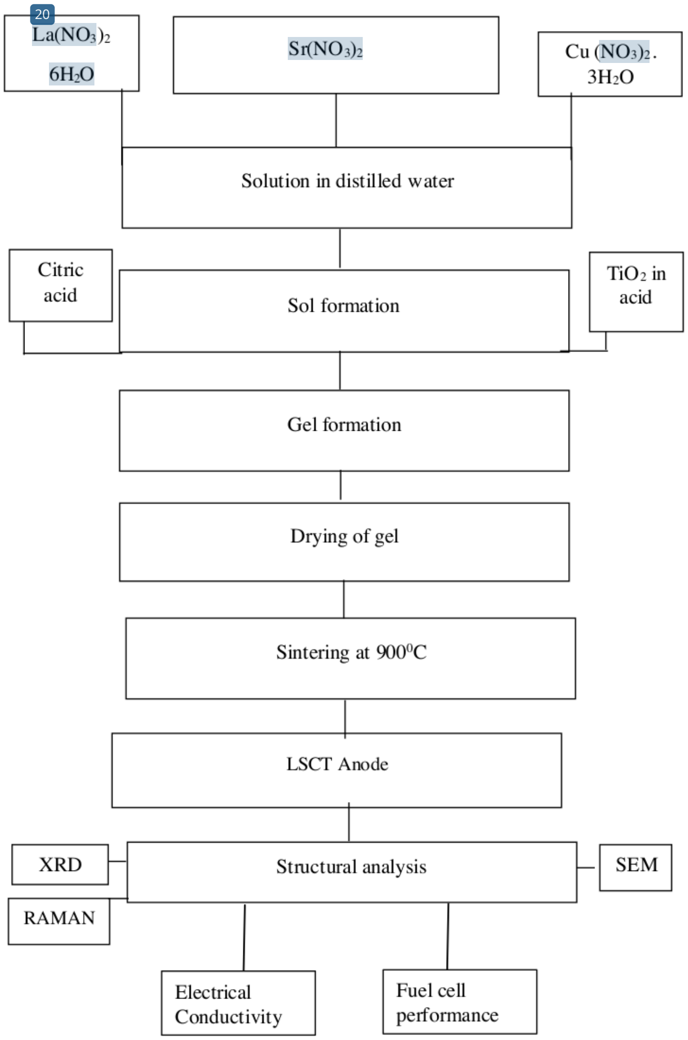


Fig 3.4: Flow diagram for anode synthesis

3.3: Characterization

3.3.1: Scanning Electron Microscope (SEM)

Scanning electron microscopy(SEM) is a technical electron microscope that employs a focused ray of electrons to overlook the face of a sample, generating signals that carry information about the face and composition of the substance. The electron ray is scrutinized in a conformation pattern, and the position of the ray is combined with the strength of the detected signals to produce an image. In a standard SEM setup, the electron ray is released from an electron gun featuring a tungsten hair cathode. SEM drivers can magnify their images up to 1- 2 million times. generally, SEM operates with acceleration voltages of over to 30 kV, furnishing a three- dimensional representation of the sample's face [49].

3.4.2: X- ray diffraction (XRD)

X-ray diffraction (XRD) is a system that utilizes X-ray shafts of a specific wavelength to interact with material patches. These shafts are dispersed depending on the crystal clear structure of the sample, creating a plot of intensity as a function of 2 theta. XRD provides information about the liquid structure of nanoparticles, as well as the unformed, crystalline, and ordered- disordered molecular arrangement parcels of the material. It also offers details on crystallography, including the crystal-clear structure of the sample, chassis parameters from the peaks, phases produced due to material processing, and the flyspeck size of the sample X-ray crystallography is a scientific system used to find out the medication of tittles of a crystalline solid in three-dimensional space. This system takes advantage of the interatomic distance of utmost liquid solids by engaging X-rays, which have wavelengths on the order of 1 angstrom (10- 8 cm). X-ray crystallography remains the primary tool used by experimenters in characterizing the infinitesimal structure of new accoutrements [50].

3.4.3: Conductivity Measurement

The four- point inquiry fashion is a extensively employed system for determining the electrical conductivity and resistivity of accoutrements . This approach involves the operation of a current through two external examinations and the dimension of the voltage across the inner examinations. The setup consists of four examinations arranged linearly in a straight line at equal distances from each other, with a sample deposited between them. The examinations are designed to make soft contact with the sample, icing a invariant force and minimizing damage to the material[51].

Chapter 4

RESULTS

4.1. UV Spectrum

The wavelength where absorption starts to increase sharply corresponds to the material's band gap. If LSC-TiO has an onset around 350 nm, it suggests a band gap of approximately 2.75 eV (using the relationship Eg=1240λonsetE_{g} = \frac{1240}{\lambda_{onset}}Eg=λonset
1240ineV,whereλonset\lambda_{onset}λonset is the onset wavelength in nm

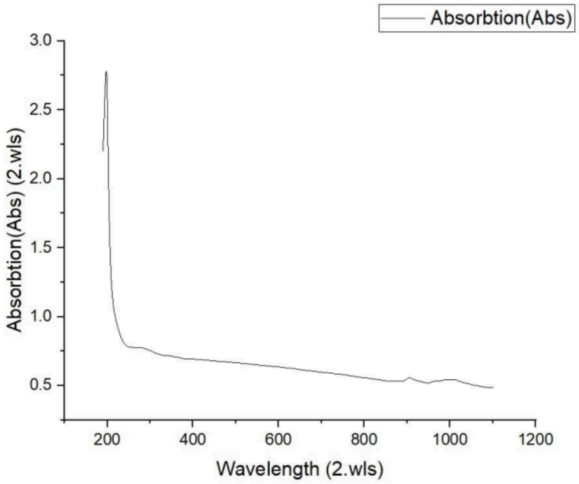


Fig 4.1 UV pattern of prepared materials La$_{0.4}$Sr$_{0.6}$Cu$_x$Ti$_{1-x}$O$_{3-\delta}$ (x = 0.02, 0.04, 0.06, and 0.08

This spectrum is from a solution containing copper (Cu^{2+}) ions, the high absorbance in the UV region is likely due to charge transfer transitions, and as the concentration of copper increases, the peak at around 200-250 nm will increase in intensity.

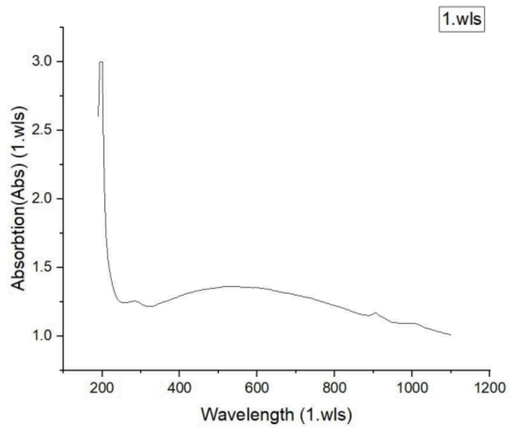


Fig 4.2 UV pattern of prepared materials $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ (x = 0.02, 0.04, 0.06, and 0.08

4.2. Microstructural analysis

Structure analysis

The "Issues and Discussion" section initiates with a structural investigation of the Titanate anode, focusing on X-ray diffraction (XRD) analysis of the $La_{0.4}Sr_{0.6}CuxTi_{1-x}O_{3-\delta}$ materials (with varying x values) sintered at 1100°C in an oxygen atmosphere for 6 hours. The XRD results reveal a single-phase, cubic perovskite structure (JCPDS 079-0188) with the space group $pm\bar{3}m$ (221), indicating that this phase forms during the high-temperature sintering process. The analysis shows a subtle shift of diffraction peaks toward lower angles as the Cu content increases, suggesting that Cu incorporation into the $La_{0.4}Sr_{0.6}TiO_3$ (LST) matrix is occurring. The diffraction peaks correspond to various crystallographic planes, and the average crystallite size, determined using the Scherrer equation for the dominant (110) peak, is calculated to be 20 nm. Notably, all observed diffraction peaks are attributed to LST, with no discernible peaks for Cu, indicating that Cu doping is within the solubility limit (up to 8 mol%) and that Cu has fully substituted Ti at the B-site. Previous studies by Li et al. and Ali et al. also reported similar doping behavior for other transition metals within their respective solubility limits, with no additional peaks corresponding to these metals. Furthermore, energy-dispersive spectroscopy (EDS) analysis in earlier studies identified La, Sr, Ti, and O as the primary elements in the material, with trace amounts of transition metals (Ni, Fe, Co, and Zn) present. This further supports the successful doping of Cu into the LST structure, as evidenced by the absence of Cu-specific peaks in the XRD patterns.

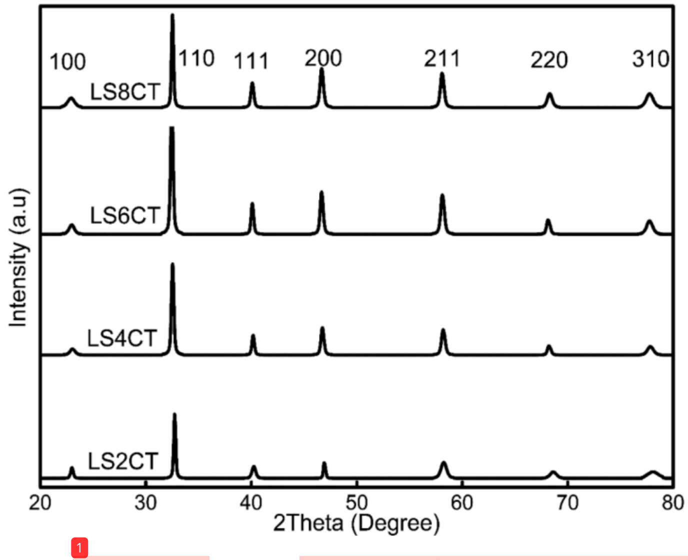


Fig 4.3 XRD pattern of prepared materials $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ (x = 0.02, 0.04, 0.06, and 0.08

4.3. Microstructural analysis

This section presents the microstructural investigation of the as-prepared anode sintered at 1000°C, as shown in Figure 2. The findings indicate that an increase in the concentration of Cu at the B-point leads to the formation of well-distributed patches within the material. The microstructural examination reveals a uniform distribution of these patches throughout the matrix, with voids also visible in the micrographs, suggesting the presence of porosity. SEM images confirm the successful sintering of the materials. Additionally, both the pore size and crystallite size change with Cu concentration. Among the samples studied, the LS8CT sample exhibits a well-formed morphology and enhanced porosity, which promotes higher gas diffusivity and improved electron transfer during cell operation. As a result, LS8CT shows superior conductivity and performance compared to the other samples. Furthermore, the average pore size observed is below 30 nm, indicating a fine distribution of pores, which likely contributes to the improved conductivity and overall performance of the material.

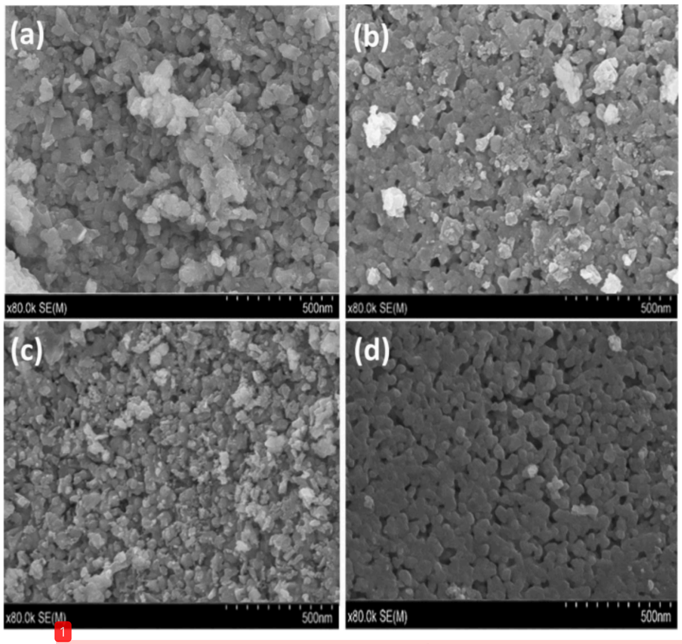


Fig4.4 SEM of the prepared anode samples $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ (x = 0.02, 0.04, 0.06, and 0.08).

4.4. Conductivity

To ensure optimal performance of the energy cell device, the anode materials must be matched with other components and maintain thermal stability at elevated temperatures. The electrical conductivity of the anode materials was evaluated in a 5% H_2 atmosphere across a temperature range of 400°C to 600°C, with the results shown in Figure 1. The data show that conductivity increases with temperature, suggesting a metallic behavior. Under reducing circumstance, a notable rise in conductivity was observed, accompanied by a transition from semiconducting to metallic properties. The reduction of $La_{0.4}Sr_{0.6}CuxTi_{1}-xO_{3-\delta}$ materials at high temperatures led to a significant increase in n-type conductivity and a shift from semiconducting to metallic behavior. Among the materials tested, LS8CT exhibited the highest conductivity at 4.21 S/cm, outperforming LS6CT, LS4CT, and LS2CT. The superior conductivity of LS8CT can be attributed to its well-formed structure and enhanced porosity, as depicted in Figure 2(d), when compared to the other samples. The improved conductivity at elevated temperatures is likely a result of sintering at 1000°C, which may have increased the contact between patches and facilitated the formation of voids that contribute to the conduction process.

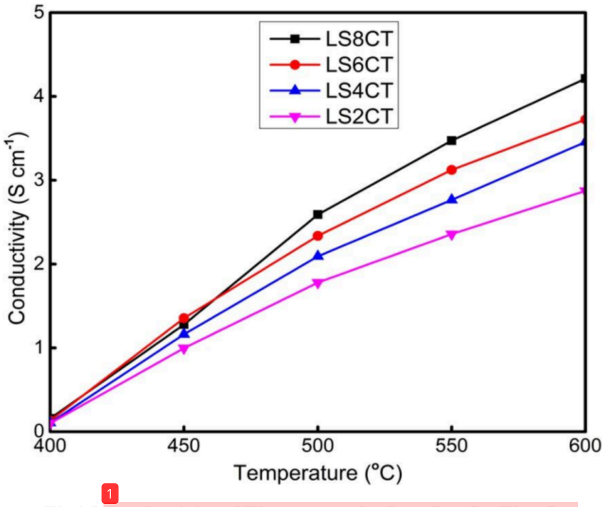


Fig4.5 Conductivity of Titanate anodes $La_{0.4}Sr_{0.6}Cu_xTi_{1-x}O_{3-\delta}$ ($x = 0.02, 0.04, 0.06$, and 0.08)

Chapter 5

DISCUSION

The electrical conductivity of the titanate-based perovskite, La0.4Sr0.6Cu0.08Ti0.92O3-δ anode material is 4.21 S cm−1 at 600°C. This value proves handy for a relative comparison of conductivity of LS8CT with other titanate based anode materials. Jiang et al examined the electrical conductivity and thermal expansion behavior of Lanthanum-doped SrTiO3 materials for solid oxide cell electrode and interconnect. The researchers established that under the temperature of 600°C the conductivity of LS8CT was 4.21 S cm−1 making the material to have high conductivity compared to other titanate-based materials. On the other hand, Li2TiSiO5 has been studied as a low-potential high-capacity anodic titanium-based material for lithium batteries. However, the search results do not give the conductivity of Li2TiSiO5 directly. Another titanate-based anode material is Lithium titanate (Li4Ti5O12) which has also been used initially in the lithium-ion batteries. From the search results there are no direct numerical values given for the conductivity of Li4Ti5O12, the information shows that in most cases XRD and SEM are employed in distinguishing the structure/ morphology of these materials.

X-ray diffraction (XRD) and scanning electron microscopy (SEM) were used to characterize the structural and microstructural properties of the titanate-based perovskite anode material, La0.4Sr0.6CuxTi1-xO3 (LSCXT). The XRD study of the synthesized LSCXT anodes sintered at 1100°C in oxygen supports all the previous identification and further confirms that Cu has been successfully incorporated in LST lattice since the XRD peaks are shifted slightly towards the smaller angle with an increase in Cu concentration. The average crystallite size calculated using the Scherrer equation for the (110) peak was around 20 nm, and the absence of discernible Cu peaks in the XRD patterns suggested that up to 8 mol% Cu doping occurs within the solubility limit, with complete doping in the Ti B-site, consistent with previous studies on doping of other transition metals in LST. SEM investigating further revealed that as the Cu concentration on the B-site increases, the anode materials exhibit well-aggregated particles with a homogeneous distribution throughout the material, with the presence of voids within the micrographs indicating the existence of porosity in the prepared samples, which can facilitate gas diffusion during fuel cell operation. The SEM analysis also confirmed the good sinterability of the anode materials, suggesting their ability to form a well-densified microstructure during the high-temperature sintering process. Among the LSCXT compositions, the LS8CT (La0.4Sr0.6Cu0.08Ti0.92O3-δ) sample exhibited a well-prepared morphology with enhanced porosity compared to the other samples, with an average particle size detected to be less than 30 nm, indicating a fine particle size distribution. A fine particle size can contribute to several advantages, such as increased surface area, improved sinterability, and enhanced ionic and electronic conductivity due to the reduced diffusion path lengths. The enhanced porosity and fine particle size distribution of the LS8CT sample are expected to facilitate improved gas diffusion and electron transfer during fuel cell operation, leading to better overall electrochemical performance compared to the other LSCXT compositions. These structural and microstructural characteristics are crucial in determining the functional properties of titanate-based perovskite anode materials for solid oxide fuel cell and lithium-ion battery applications.

La0.4Sr0.6Cu0.08Ti0.92O3-δ (LS8CT) titanate-based perovskite anode material over other LSCXT compositions. The most notable advantage of the LS8CT sample is its enhanced porosity, as revealed by the scanning electron microscopy (SEM) analysis. The SEM micrographs showed that the LS8CT sample exhibited a well-prepared morphology with a higher degree of porosity compared to the other LSCXT compositions. This increased porosity is expected to facilitate improved gas diffusion during fuel cell operation, which is a crucial factor for efficient electrochemical performance. Another key advantage of the LS8CT anode material is its fine particle size distribution. The average particle size of the LS8CT sample was detected to be less than 30 nm, indicating a narrow particle size range. A fine particle size distribution can contribute to several beneficial properties, such as increased surface area, improved sinterability, and enhanced ionic and electronic conductivity due to the reduced diffusion path lengths. These characteristics are highly desirable for anode materials in solid oxide fuel cell applications, as they can lead to enhanced electrochemical performance. The combination of the LS8CT sample's enhanced porosity and fine particle size distribution is expected to result in superior gas diffusion and electron transport during fuel cell operation, ultimately leading to better overall electrochemical performance compared to the other LSCXT anode compositions. These advantageous microstructural features make the LS8CT material a promising candidate for further development and optimization as a high-performance anode for solid oxide fuel cell applications. Another potential challenge is the sourcing of raw materials, particularly the rare earth elements lanthanum (La) and strontium (Sr) that are present in the LS8CT composition. Securing a reliable and sustainable supply of these materials in the quantities required for large-scale production may be difficult, considering the geopolitical and environmental concerns associated with rare earth element mining and processing. Additionally, maintaining the desired copper (Cu) doping level and distribution during large-scale manufacturing will require careful process control and optimization to ensure the successful incorporation of Cu into the LS8CT lattice.

CONCLUSION

Cu-doped $LaSrTiO_3$ is shown in this study to be a suitable anode material for the solid oxide fuel cells through comparatively high high-temperature stability and structural characteristics. The sol-gel synthesis of LSCT offered good control over the phase constitution and morphology of the perovskite, exhibiting a cubic structure with crystallite size of <30 nm as observed by SEM and XRD studies. The grain size was calculated by using the Scherrer's formula and found to be about 20 nm, which is otherwise fine and uniform.The four probe electrical conductivity measurement revealed that the LSCT delivered a maximum conductivity of 4.21 S/cm at 600°C. This high conductivity and the mechanical strength of the material at high temperatures, fully fits it for use as SOFC anode. In addition, there are some changes in the electrical and catalytic properties by the introduction of Cu into $LaSrTiO_3$ lattice which still enhances fuel cell performance.Therefore, synthesis and characterization results, in the large extent, confirm the suitability of LSCT as the potential SOFC anode materials combining high strength, proper electrical conductivity, and high catalytic activity. This work presents subsequent framework investigations into enhancement of LSCT and other perovskite materials for future higher SOFC technologies.

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